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The Ohio State University

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The Ohio State University

ElectroScience Laboratory

Department of Electrical Engineering
Columbus, Ohio 43212

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16. Abstract (Limit: 200 words)

This report presents the fourth annual review of research at Ohio State sponsored by the Joint Services Electronics Program (JSEP). The research is in the area of electromagnetics and the specific topics are: (1) Diffraction Studies; (2) Hybrid Techniques; (3) Antenna Studies; (4) Time Domain Studies; (5) Transient Signature Measurements of Radar Targets for Inverse Scattering Research.

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I. INTRODUCTION

This report presents the fourth annual summary of research at Ohio State sponsored by the Joint Services Electronics Program (JSEP). The research is in the area of electromagnetics and the specific topics are: (1) Diffraction Studies; (2) Hybrid Techniques; (3) Antenna Studies; (4) Time Domain Studies; and (5) Transient Signature Measurements of Radar Targets for Inverse Scattering Research.

The following sections summarize the significant accomplishments of the program (Section II) and the research by work unit (Section III). Researchers and their publications are listed under each work unit. A listing of the present research programs at the Laboratory and all reports and papers published by the Laboratory during the past year are given in the appendices.

II. SIGNIFICANT ACCOMPLISHMENTS

The study of the Uniform Geometrical Theory of Diffraction continues to be one of our major efforts. This work is basic to the development of computer codes for calculating the patterns of reflector antennas and antennas on aircraft, missiles, satellites, ships and in other environments and for calculating the radar cross section of a wide range of objects. In the present period, significant contributions were made in radiation and scattering from impedance loaded surfaces, radiation from antennas mounted close to edges, radiation from antennas on or near structures with vertices (corners) and scattering from finned cylinders of finite length. The radiation studies are helping us to develop more general computer codes on other programs for the analysis of antennas on or near complex structures such as ships and planes. The scattering work is helping on programs involving radar cross section studies and target identification.

Using combined GTD and moment method (hybrid) techniques, a numerically derived solution has been obtained for diffraction from a perfectly-conducting planar surface which is smoothly terminated by a circular cylinder. The solution is valid not only in the region away from the refraction boundary, but also in the region near to it. This solution is very useful in optimizing practical terminations to flat plate structures such as horn antennas. It is now a straightforward procedure to design a horn antenna with curved edges for a specified side-and back-lobe level in the E-plane. The curved transition also helps to match the waveguide feed to the horn and the aperture of the horn to free space resulting in substantially improved bandwidth and VSWR compared to a conventional horn.

Many practical antenna applications involve monopole-type antennas mounted near the edge of a complex surface or structure. A solution has been obtained for a wire antenna mounted near a wedge of arbitrary angle or near a corner, and surface patch modelling of complex shapes has been extended by development of a non-rectangular, or polygonal, patch model. These developments are being used to improve moment method computer codes on other programs for analyzing antennas on complex structures such as buildings, planes and ships.

In the area of time domain studies, we are predicting scattered waveforms for objects of increasing complexity, finding target-dependent excitation waveforms and processing algorithms to identify and optimize responses from specific targets, and determining effects of noise and signal bandwidth on the detection and identification of radar targets. This work has direct application to non-cooperative target recognition.

The free space scattering range at The Ohio State University ElectroScience Laboratory has been modified and calibrated to obtain accurate polarization matrix information on selected reference targets including a 2:1 cylinder, a 2:1 cylinder with spherical cap, a 2:1 oblate spheroid and a 4:2:1 ellipsoid. The computer-controlled measurement process includes a no-target measurement and measurements of at least two reference spheres along with every measurement set. For each target and aspect angle, the frequency is stepped over a complete microwave band (1-2 GHz, 2-4 GHz, 4-8 GHz and 8-11 GHz) as complex cross-section data are recorded and stored. Computer data processing is done as a separate step and involves subtraction of the signal scattered from support pedestal and background along with normalization and linearity checks using the reference spheres at each frequency.

Nine graduate students have been involved with this program over the past year and over the past three years, with the support of this program, there have been 7 students granted the M.Sc. degree in Electrical Engineering and 7 students granted the Ph.D. degree in Electrical Engineering.

III. RESEARCH SUMMARY

A. Diffraction Studies

Researchers: R.G. Kouyoumjian, Professor (Phone: (614) 422-7302)
P.H. Pathak, Research Scientist and Adjunct Assistant Professor
N. Wang, Senior Research Associate
R. Tiberio, Visiting Professor
T. Jirapunth, Graduate Research Associate
M. Buyukdura, Graduate Research Associate
S. Goad, Graduate Research Associate

Accomplishments

During the present contract period, the work accomplished in extending the uniform geometrical theory of diffraction (UTD) has been substantial. This research, and the technical papers based on this research which have recently appeared (or have been accepted for publication) are described below.

1. Diffraction at Convex Surfaces

a. Perfectly-conducting surfaces

Following the paper "On a Uniform GTD (UTD) Analysis of the Scattering of EM Waves by a Smooth Convex Slurface" by Pathak, Burnside, and Marhefka, which was published late last year in the September 1980 issue of the IEEE Trans. on Antennas and Prop., the UTD solutions to two other related problems have been developed. In the aforementioned paper, the source and the observer are both positioned off the smooth convex surface. Thus, the UTD solution described in that paper is commonly referred to as the "scattering solution". The two other related problems of interest and importance which have been analyzed recently are those for which only the source or the observer lie on the surface, and also for which the source and observer are both on the surface, respectively. The problem corresponding to the case when the source or the observer is off the surface is commonly referred to as the "radiation problem"; whereas, the one dealing with the source and observer on the surface is referred to as the "coupling problem". The solution to the radiation problem is useful and important for analyzing the radiation patterns of antennas on a smooth convex surface such as an aircraft, spacecraft, or a missile. Likewise, the solution to the mutual coupling problem arises in the analysis of arrays of antennas placed conformally on smooth convex surfaces such as those described above.

The UTD ray solutions to these important radiation and coupling problems have been obtained and described in the two additional papers which have recently appeared in print; in particular, these most recent publications are:

"A Uniform GTD Solution for the Radiation from Sources on a Perfectly-Conducting Surface" by P.H. Pathak, N. Wang, W.D. Burnside, and R.G. Kouyoumjian; IEEE Transactions on Antennas and Propagation, Vol. 29, No. 4, July 1981, pp. 609-621.

"Ray Analysis of Mutual Coupling Between Antennas on a Convex Surface", by P.H. Pathak and N. Wang; IEEE Transactions on Antennas and Propagation, Vol. 29, No. 6, November 1981, pp. 911-922.

The above mentioned UTD solutions for scattering, radiation, and mutual coupling, which are associated with antennas radiating in the presence of an arbitrary, smooth perfectly-conducting convex surface represent an important and useful contribution to the area of ray methods for analyzing the EM radiation and scattering from complex structures. It is noted that the effects of surface ray torsion on the diffracted fields are explicitly identified in these solutions. Here, the diffracted fields are associated with surface rays as well as with rays shed from the surface rays. It is noted that the surface rays traverse geodesic paths on a convex surface. On an arbitrary convex surface, these geodesic surface ray paths are in general torsional (i.e., they possess non-zero torsion). Some typical numerical results for the UTD based radiation pattern and mutual coupling calculations for antennas on a smooth convex surface which appeared in the two recent papers are shown in Figures A-1 to A-6.

It is clear from Figure A-4 that the agreement between the UTD solutions and corresponding measurements is very good for the complex spheroidal shape. Of course, the agreement between the UTD solutions and exact (eigenfunction) series solutions for the circular or elliptic cylinder and cone geometries is also excellent as shown in Figures A-1, A-2, A-5, and A-6. The present UTD solutions for coupling are marked as OSU solutions (with the legend XXX) in Figures A-5 and A-6. The UI and

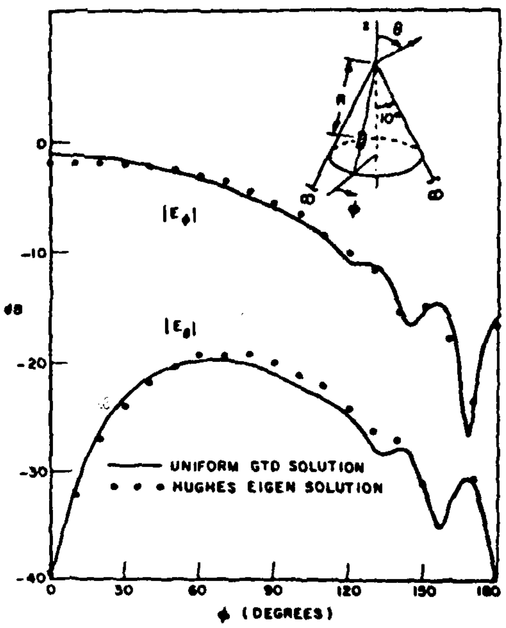

Figure A-1. Radiation patterns of a radial slot in a cone.

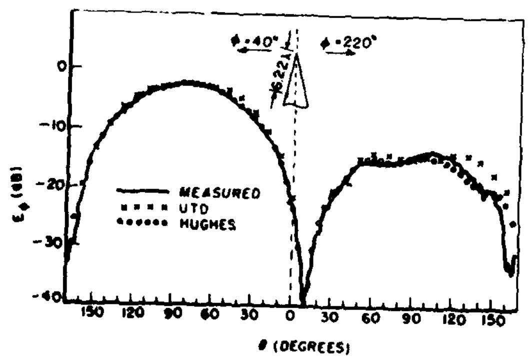

Figure A-2. $|E_\phi|$ radiation pattern of a radial slot in a cone (see cone geometry in Figure A-1).

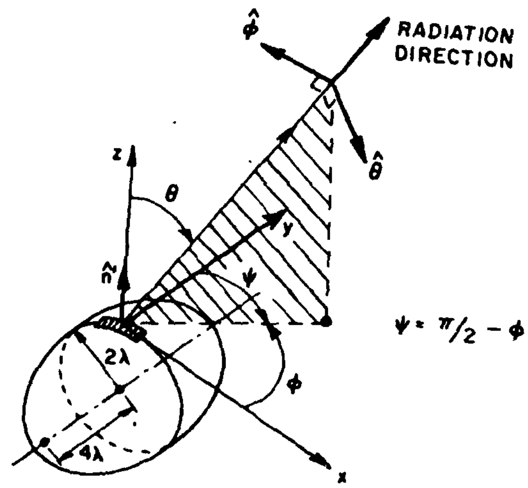

Figure A-3. Prolate spheroidal geometry.

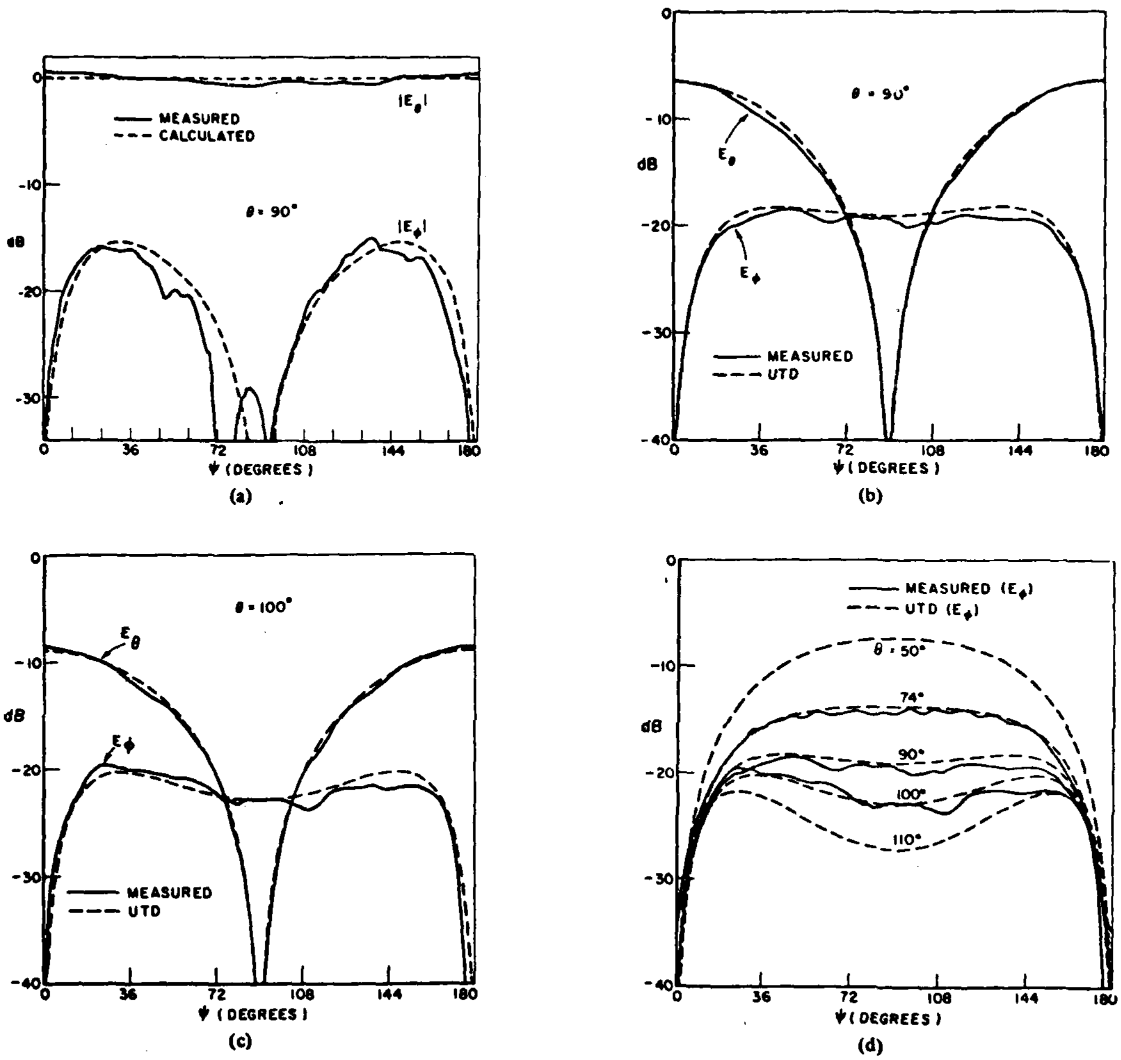

Figure A-4. Radiation patterns of antennas on a prolate spheroid. (a) Pertains to the pattern of a n' directed monopole antenna (at the source location in Figure A-3); (b), (c), and (d) pertain to the patterns of an x-directed rectangular slot (at the source location in Figure A-3) on a spheroid. The dimensions of the prolate spheroid are shown in Fig. A-3.

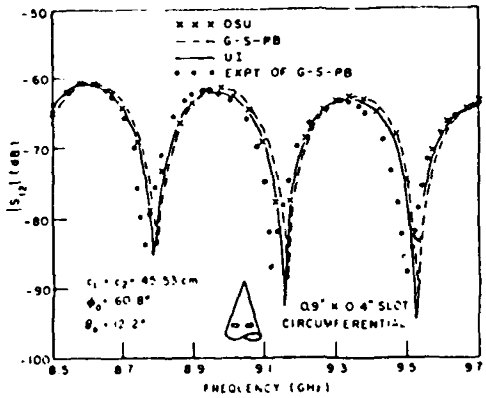

Figure A-5. Coupling coefficient S_{12} between two circumferential slots on a cone versus frequency. The radial separation between the slots is $|C_1-C_2|$ and angular separation is ϕ_0. The cone half angle is θ_0.

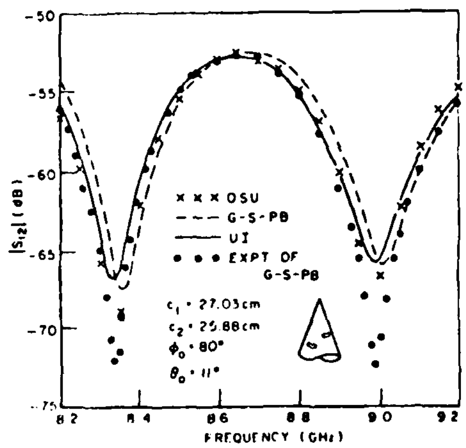

Figure A-6. Coupling coefficient S_{12} between two circumferential slots on a cone versus frequency. The radial separation between the slots is $|C_1-C_2|$ and angular separation is ϕ_0. The cone half angle is θ_0.

G-S-PB solutions shown in these figures for comparison correspond to those of S.W. Lee (IEEE Trans. AP., Vol. 26, No. 6, pp. 768-773, Nov. 1978), and of Golden, Stewart, and Pridmore-Brown (IEEE Trans. AP., Vol. 22, pp. 43-48, 1974), respectively. The reader is referred to our aforementioned paper dealing with the UTD analysis of mutual coupling for further details on the comparisons of these different solutions.

b. The radiation and scattering from cylindrical surfaces with a dielectric coating of uniform thichness

A study of the electromagnetic radiation and scattering from a conducting surface with dielectric loading is of great interest in that it provides an understanding of the effects of the loading on the scattered fields. An important application of coating is to control the electromagnetic scattering characteristics from conducting bodies such as an aircraft, missile, satellite, etc. Also, it is useful in predicting the radar cross-section of structures made of composite materials or conducting bodies coated with dielectric materials.

In the case of a conducting surface coated with a thin layer of dielectric with a uniform thickness, the surface can be conveniently viewed as an impedance surface with a constant surface impedance. This simplified surface-impedance model of a coated cylinder has been studied during the first year of a three-year research program for the basic diffraction studies. We have developed a high frequency solution for the problem and were able to predict the resonance phenomena of the radar cross-section of a circular cylinder with a constant surface impedance. It was found that surface waves with almost pure imaginary propagation constant traverse around the cylinder surface with very low attenuation, and interfere with each other constructively such that they add in phase to give the distinctive resonance phenomena in the radar cross-section. Numerical values for the propagation constant of the surface wave, which are related to the Regge poles of the impedance cylinder, have been found. Also, a criterion for predicting resonance has been established and the correlations between the resonance, the Regge poles, and the natural frequencies of the impedance cylinder have been demonstrated.

It should be noted that the surface-impedance model is valid only for low loss thin dielectric sheets over the conducting surfaces. For a coating with moderate thickness, a more accurate approach should be pursued. During the second year of a three-year research program, work has been in progress to investigate the radar cross-section of a conducting cylinder coated by a dielectric layer of uniform thickness.

Using the standard Watson's transformation techniques, the rigorous eigenfunction solution for the coated circular cylinder is cast into a ray solution. The backscattered field from the coated cylinder, illuminated with an incident plane wave, is obtained by summing the geometrical-optics contribution and the surface-wave contributions which include all the multiply-encircling surface waves. The parameter of fundamental importance associated with surface-wave fields is the propagation constant of the surface wave. The propagation constant is related to the Regge poles of the coated cylinder. By a combination of numerical procedures, these Regge poles were obtained by solving the high frequency approximation of a transcendental equation.

Once the dominant Regge poles are known, the surface-wave contributions to the backscattered field of a coated cylinder are readily determined. Summing the geometrical-optics and the surface-wave contributions, the normalized backscattering width of a coated cylinder is calculated as a function of frequency. The thickness of the dielectric coating t is held to be constant in its electric length in terms of the free-space wavelength λ_0. Figure A-7 presents the numerical values of the normalized echo width as a function of ka, where a is the radius of the conducting cylinder. The results obtained from the eigen-function solution are also plotted in the figure. One observes the excellent agreements for large ka between the high-frequency ray solution and the eigenfunction solution. It should be noted that only the dominant surface wave is employed in the calculation, however all the multiply-encircling rays are included in a self-consistent fashion. Another example is illustrated in Figure A-8. Backscattering width is presented for a perfectly conducting cylinder coated with a dielectric layer of thickness $t/\lambda_0 = 0.41$, and the relative dielectric constant ε_r is equal to 2.56. Both the TE and TM cases are included. With only the dominant surface wave contribution included, the agreement between the high frequency ray solution and the eigenfunction solution is still satisfactory. The possibility of improving the ray solution by including higher-order surface waves and/or using a more accurate high frequency approximation to the transcendental equation needs to be further investigated.

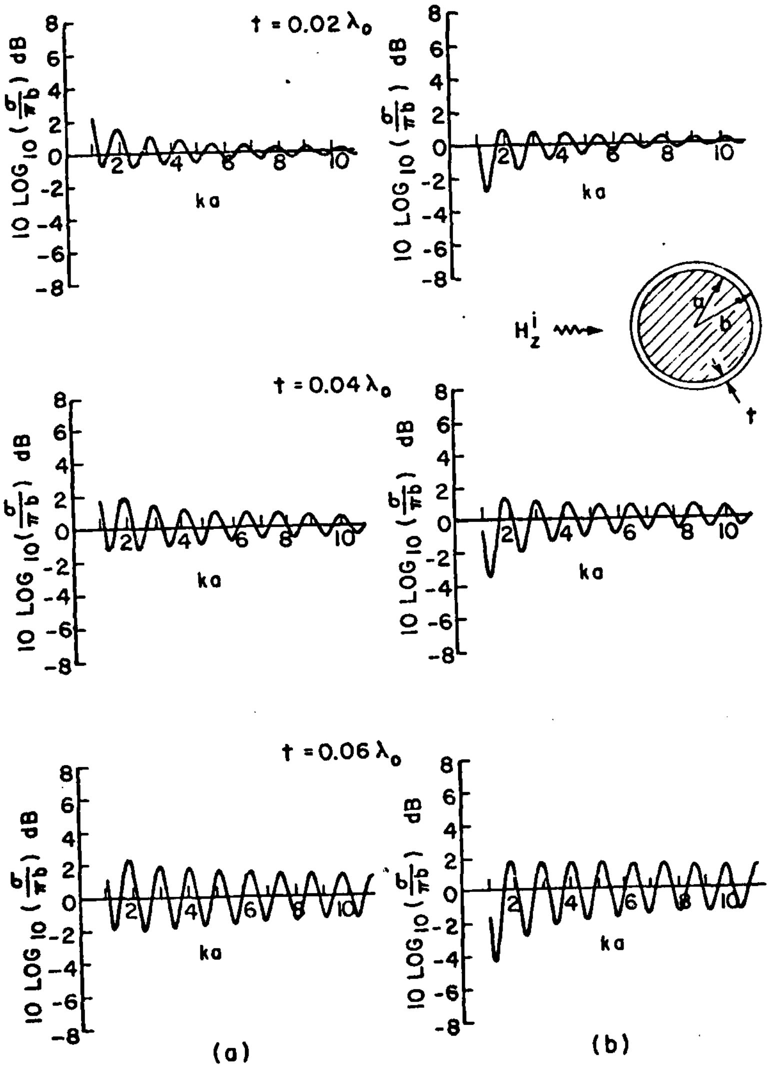

Figure A-7. Backscattering width of an infinitely long, coated (ε_r=4), perfectly conducting cylinder: (a) high frequency ray solution, (b) exact eigenfunction solution.

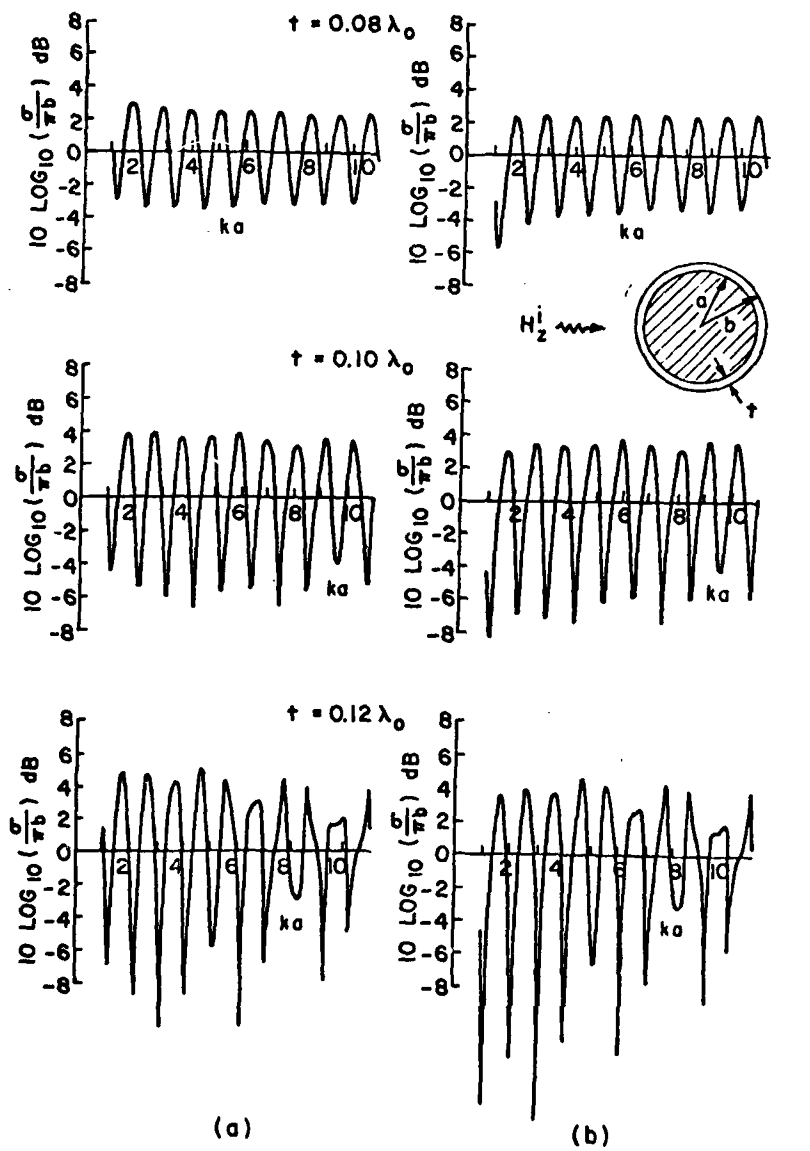

Figure A-7. (Continued) Backscattering width of an infinitely long, coated, perfectly conducting cylinder: (a) high frequency ray solution, (b) exact eigenfunction solution.

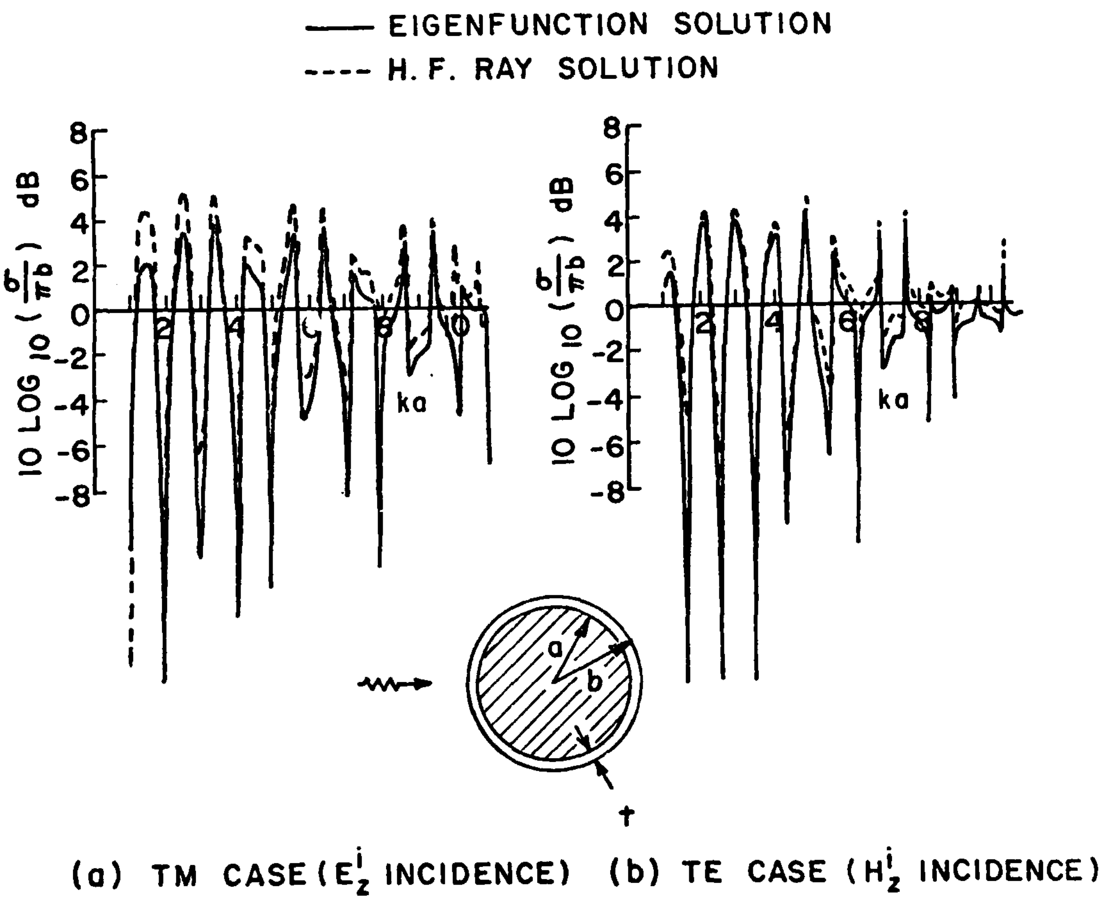

Figure A-8. Backscattering width of an infinitely long, coated, perfectly conducting cylinder (ϵ_r=2.56, t/λ=0.41).

Work is now in progress to investigate the bistatic scattering and radiation from the coated cylinder. Emphasis will be placed on the development of a solution in the transition region around the shadow boundaries.

c. Partially coated perfectly conducting surfaces

Two papers are being prepared on the subject of asymptotic high-frequency radiation from a magnetic line source or a magnetic line dipole located on a uniform impedance surface which partially covers a perfectly-conducting surface. This work is of interest in the study of fuselage mounted airborne slot antennas where, for example, it may be desired to increase the radiation near the horizon or shadow boundary. These papers which will be submitted shortly for publication are:

"An Approximate Asymptotic Analysis of the Radiation from Sources on Perfectly-Conducting Convex Cylinders with an Impedance Surface Patch" by L. Ersoy and P.H. Pathak; to be submitted for publication to the IEEE Transactions on Antennas and Propagation.

"Ray Analysis of the Radiation from Sources on Planar and Cylindrical Surfaces with an Impedance Surface Patch" by P.H. Pathak and L. Ersoy; to be submitted to J. Radio Science.

In the second paper, the impedance surface is assumed to be such that it always supports a surface wave mode for a given source. The surface wave diffraction effects are calculated via the Uniform GTD (or UTD) which employs uniform diffraction coefficients. The latter are found from the Wiener-Hopf solutions to canonical problems of surface wave diffraction by a planar two-part surface. The first paper removes the limitations placed in the analysis pertaining to the second paper in that it is also valid for impedance surfaces which do not support a surface wave-type mode.

A natural extension of the work reported in the first paper is to treat the corresponding scattering problem where the source is no longer positioned on the surface with the impedance patch (or, alternatively, this structure may be illuminated by a plane wave). A study of the scattering from such a surface is of value in that it provides an understanding of the effect of the impedance loading on the scattered fields. An interesting application is to control the electromagnetic scattering from conducting bodies such as an aircraft, missile, or a satellite, etc. Also, it is useful in the radar cross section calculations of structures made of composite materials or of conducting bodies coated with absorber materials.

An additional topic of interest which has been analyzed recently via ray methods is the diffraction by a strip with two face impedances when illuminated at grazing. While the analysis of backscattering from a strip with two face impedances has been performed for special cases; the present analysis is valid for all aspects including the forward scatter direction when the strip is illuminated at grazing (or at edge on). It is noted that the analysis in the forward scatter direction for grazing incidence is complicated because the diffraction from the leading edge produces a non-ray optical field at the trailing edge; consequently, the diffraction of this non-ray optical field from the trailing edge to yield a contribution to the field diffracted in the forward direction must be handled carefully. Here, the diffraction of the non-ray optical field is analyzed via a spectral extension of the geometrical theory of diffraction. A paper has been recently written which describes this work; namely:

"Scattering by a Strip with Two Face Impedances at Edge On Incidence", by R. Tiberio, F. Bessi, G. Manara, and G. Pelosi, submitted for publication to J. Radio Science.

d. Slope diffraction for convex surfaces

A UTD solution for the scattering of EM waves by a convex surface illuminated by a ray-optical field with a slow spatial variation at and near the point of diffraction on the shadow boundary has been developed as discussed in part (a). This solution has now been extended to the case where the incident field has a rapid spatial variation near this point. This analysis would be useful in studying the effects on antenna patterns resulting from the diffraction by convex bodies, e.g., the shadowing effects of an aircraft-fuselage on the radiation from a wing or tail mounted array, or of a ship mast on the radiation from a nearby shipboard antenna.

The extension has been carried out for the circular cylinder by considering the illumination of that cylinder by a line dipole source (in the two-dimensional case) or by a point dipole source (in the three dimensional case) in which the dipole is oriented so that its field vanishes at the point of diffraction. As a part of the future work, this solution will be generalized later to three-dimensional geometries where the rapidly-varying incident electromagnetic field emanates from a point source in the presence of an arbitrary, smooth, perfectly-conducting convex surface.

Some typical numerical results based on the UTD slope diffraction solution for the circular cylinder are shown below in Figures A-9 and A-10. The excitation for these cases is a point electric current source in Figure A-9, and a point magnetic current source in Figure A-10. In these figures, the elevation angle (θ) between the radiation direction and the cylinder axis is fixed while the azimuth angle (ϕ) changes from 0° to 360°. The source orientation for the calculations in Figures A-9 and A-10 is chosen such that the incident field (i.e., the source pattern) vanishes at one of the points of grazing incidence on the cylinder; consequently, the incident ray field is rapidly varying at that point of grazing incidnece. For these cases, the ordinary UTD analysis would predict no diffraction from the point of grazing incidence at which the incident field has a pattern null; whereas, the slope diffraction solution correctly predicts the effects of the diffraction of this rapidly varying incident ray field. The UTD slope diffraction solutions in Figures A-9 and A-10 are compared with the corresponding exact eigenfunction solutions; indeed, the agreement is very good, thereby indicating the accuracy of the UTD slope result associated with the diffraction of a rapidly varying field by a cylinder.

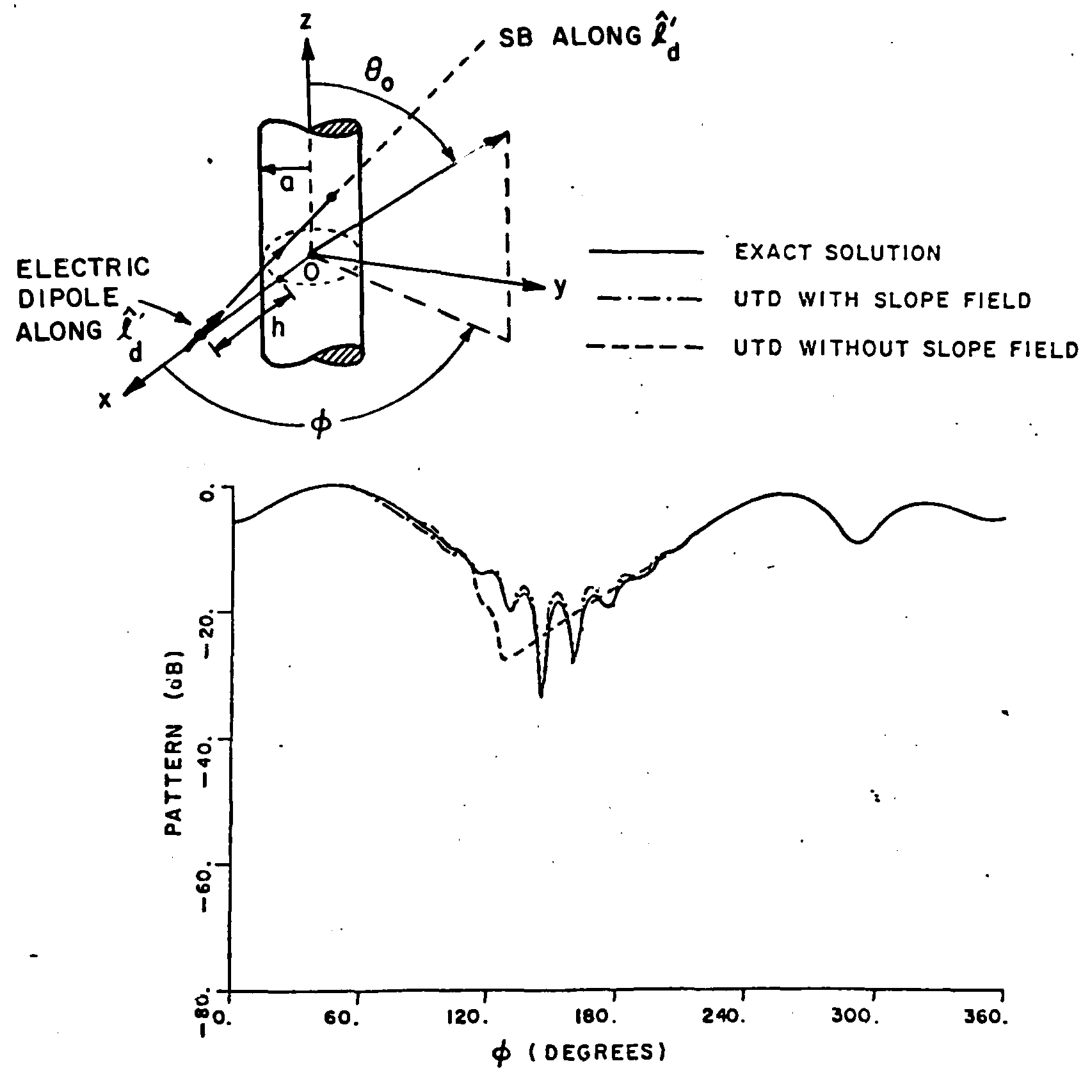

Figure A-9. The E_θ radiation [illegible] of a short electric dipole in the presence of a perfectly conducting circular cylinder. The dipole is in the $\hat{\ell}'_d$ direction, ka = 12, h = 0.5λ and θ_0 = 60°.

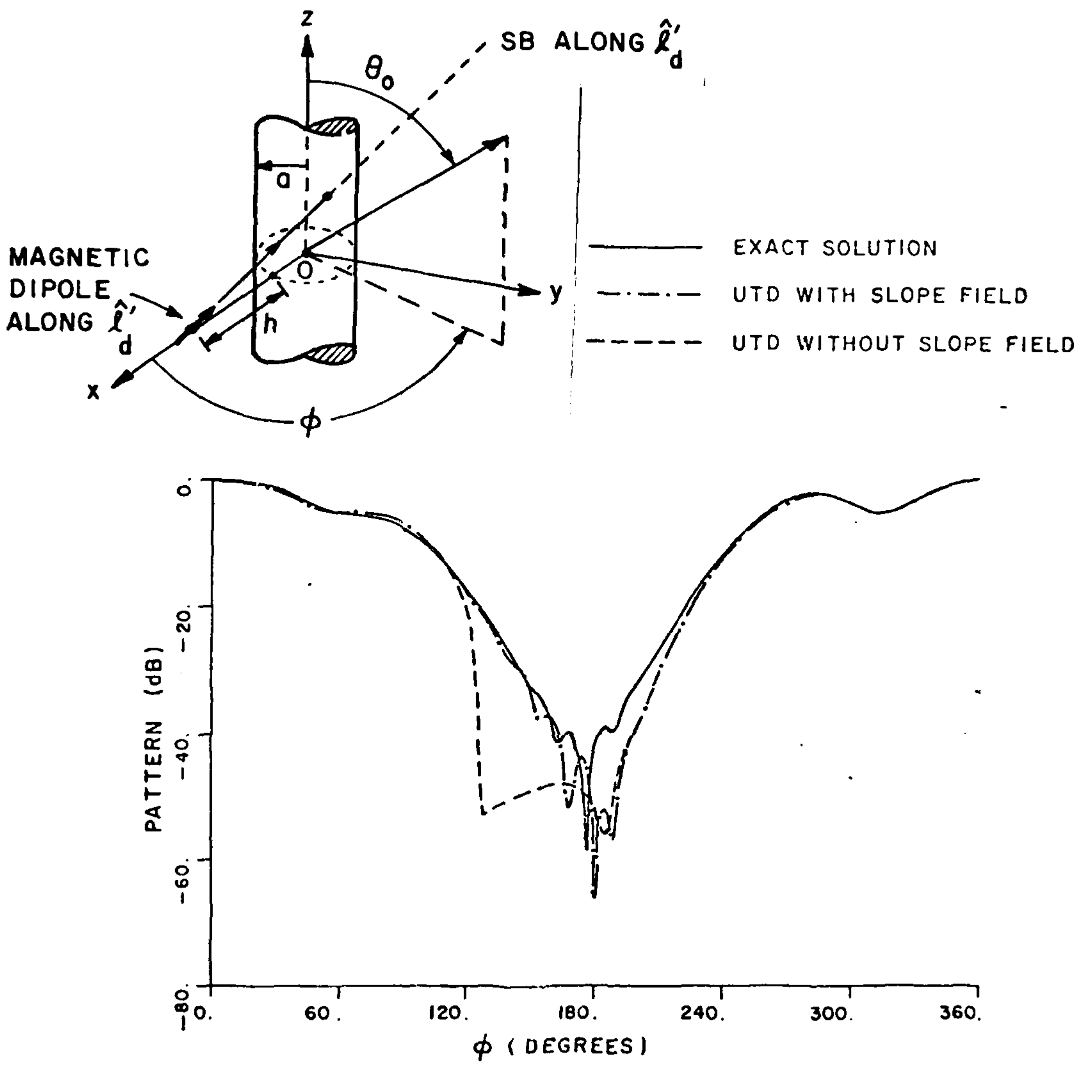

Figure A-10. The E_θ radiation pattern of a short magnetic dipole in the presence of a perfectly conducting circular cylinder. The dipole is in the $\hat{\ell}'_d$ direction, ka = 12, h = 0.5λ, and θ_0 = 60°.

2. Extensions of Edge Diffraction

a. Edge illumination by non ray-optical fields

i) Source close to an edge

In the conventional form of the Uniform GTD, it is assumed that the incident field is a ray-optical field, which implies that it is polarized in a direction perpendicular to the incident ray. In general, this requires that the source of the incident field be sufficiently far from the point of diffraction so that the component of the incident field parallel to its ray path (the component in the radial direction from the source) is negligible at the diffraction point. However, in some applications this is not the case, e.g., a monopole antenna may be mounted at or very close to the edge of a ship or the edges of wings and stabilizers. This case is also of interest in the development of the Hybrid GTD/Moment Method solution, where it is desired to calculate the input impedance of a wire antenna close to an edge.

An asymptotic solution for the diffraction of the fields of electric and magnetic dipoles close to the edge of a wedge has been obtained. The analysis proceeds as done ezrlier in developing improved wedge diffraction coefficients [1], except that the radial component of the incident field is included which makes it necessary to include higher order terms in the asymptotic approximation. In the present Uniform GTD expression, the field point must be far from the point of diffraction on the edge. An attempt is being made to overcome this limitation by representing the field of a dipole close to the edge by a spectrum of plane waves. The resulting integral representation for the diffracted dipole field would then be asymptotically approximated to obtain the desired solution. It should be noted that the field close to the edge can be calculated for plane wave illumination.

A second method for removing the aforementioned limitation is to employ a convergent, spherical wave representation for the field of a dipole close to an edge. The solution enables us to calculate edge diffraction in the paraxial region, where the present asymptotic solution fails. It is hoped that the spherical wave solution can be combined numerically with the asymptotic (or UTD) solution so that we will have a more useful computational algorithm for edge diffraction.

From the local behavior of edge diffraction, one expects to be able to extend these results to curved wedge geometries and to use them to calculate the radiation from complex structures.

ii) Transition region fields incident on the edge

Several papers have been written on the diffraction by a pair of nearby, parallel edges, where one edge lies on the shadow boundary of the other. A configuration of this type may be a part of practical antenna and scattering geometries. The solution to this problem requires an extension of the Uniform GTD, which is valid only for ray-optical fields incident on the edge, because the shadow boundary field illuminating the second edge is not a ray-optical field. These papers are:

"An Analysis of Diffraction at Edges Illuminated by Transition Region Fields" by R. Tiberio and R.G. Kouyoumjian; submitted to J. Radio Science.

"Calculation of the High-Frequency Diffraction by Two Nearby Edges Illuminated at Grazing Incidence" by R. Tiberio and R.G. Kouyoumjian; submitted to the IEEE Transactions on Antennas Propagation.

b. Edge-excited surface rays

A paper entitled "A Uniform GTD Analysis of Edge-Excited Surface Rays" by P . Pathak and R.G. Kouyoumjian is being written; it will be submitted to the IEEE Transactions on Antennas and Propagation.

This paper describes a Uniform GTD (or UTD) analysis of surface diffracted rays which are excited by a curved edge in an otherwise smooth convex surface. Such a curved wedge configuration occurs as a part of many practical antenna and scattering shapes, e.g., the base of conical and cylinderical structures, and the trailing edge of wings and stabilizers.

The excitation of surface waves on a convex surface can be associated with an "equivalent current" located at the edge. The strength of this equivalent current is shown to be directly related to the field of the edge diffracted space ray. Its strength is fixed to its value at the shadow boundary when calculating the surface diffracted field in the shadow region, whereas it changes according to the Kouyoumjian-Pathak edge diffraction coefficient [2] when calculating the field in the lit region (i.e., on the lit side of the surface shadow boundary). Thus, in the lit region, this solution reduces uniformly to the usual edge diffracted space ray field outside the surface shadow boundary transition region even though it depends on the nature of the convex surface near the edge for field points in the shadow as well as the lit portions of this transition region. The present solution does not include the case where there is a confluence of edge and curved surface shadow boundaries; this case is being investigated and it forms a part of the future research. A hybrid GTD-MM solution to this problem is also proposed in a separate work unit (Hybrid Techniques); the hybrid solution should provide a useful check on the asymptotic solution and it is currently in progress.

The present solution can be readily extended to the concave surface of a curved wedge. The equivalent edge currents are now used to determine the field of the mixture of space rays and whispering gallery modes which have been prescribed by Felsen [3]. Note that the space rays are, in general, multiply reflected from the concave surface.

c. Slope diffraction for edges

If the field incident on the edge of a perfectly-conducting wedge does not have a rapid spatial variation transverse to the direction of incidence, the diffracted field is directly proportional to the field incident at the edge, and it can be calculated using the Kouyoumjian-Pathak edge diffraction coefficient [2]. However, if the field incident on the edge has a rapid spatial variation, a second term is required. This is proportional to the spatial derivatives of the incident field at the edge and is known as the slope diffraction term. The slope diffraction term ensures that the spatial derivatives of the pattern function are continuous at the shadow and reflecting boundaries, so that there are no "kinks" in the calculated high-frequency pattern. The need for a higher order term of this type may also arise in the case of diffraction at a convex surface, as was pointed out in Section 1d.

We have employed several methods to obtain the dyadic slope diffraction coefficient for an ordinary wedge, and although this coefficient has been reported in the literature [4], its derivation has not been published. Recently, some higher order terms, which are proportional to the second spatial derivatives of the incident field, have been obtained., Also, we have attempted to generalize our expression for slope diffraction to the curved wedge, i.e., a wedge formed by intersecting curved surfaces. However, in making some careful checks, it has been found that the expression is noticeably in error at the reflection boundary of a curved wedge in some cases. We are presently trying to solve this problem.

d. Diffraction by a thin dielectric half-plane

The diffraction by a thin dielectric half plane is an important canonical problem in the study of the diffraction of electromagnetic waves by penetrable bodies with edges. The excitation for this problem can be either an electromagnetic plane wave, or a surface wave incident along the dielectric surface; both types of excitation are considered.

For sufficiently thin dielectric half planes, solutions based on the Wiener-Hopf technique can be obtained if one approximates the effect of the thin dielectric slab by an impedance boundary condition. This analysis begins by bisecting the semi-infinite dielectric half plane by an electric wall in the first case, and by a magnetic wall in the second case. The problem of plane (or surface) wave diffraction by the dielectric half plane is then constructed by appropriately superimposing the corresponding solutions for the electric and magnetic wall bisections, respectively. This procedure is expected to yield a dielectric half plane diffraction coefficient which is far more accurate than that obtained recently by Anderson for the case when the incident plane wave electric field is parallel to the edge of the thin dielectric half plane [5], because the latter analysis employs an approximate "equivalent" polarization current sheet model for the thin dielectric half plane. The approximation in [5] contains only a part of the information present in the more general approach being employed in our work; consequently, it is found that the analysis in [5] yields a diffraction coefficient which is valid only for an extremely thin dielectric half plane. Furthermore, the equivalent polarization current approximation leads to a more complicated Wiener-Hopf analysis when the magnetic field is parallel to the edge; the latter case has not been treated by Anderson [5]. It is also noted that the Wiener-Hopf factors for the case treated by Anderson [5] do not appear to be well behaved for near edge on plane wave incidence cases. In contrast, the Wiener-Hopf factors being employed in our work are based on Weinstein's factorization procedure [6] which overcomes the difficulties present in [5].

At the present time, the diffraction coefficients for the two-dimensional case of both TE and TM plane and cylindrical wave excitation of the thin dielectric half-plane have been obtained, and they are being tested for accuracy. The case of TE and TM surface wave excitation of the thin dielectric half-plane is currently being analyzed. It is expected that this part of the study will be completed in the year ahead. In addition, the extension of the two-dimensional solutions to treat the three-dimensional problems of one diffraction of obliquely incident plane, conical, and spherical waves by a thin dielectric half-plane are also being investigated as a part of the future work on this important problem.

Some preliminary numerical results for the TE and TM cylindrical wave diffraction by a thin dielectric strip which are based on the present UTD solution are shown in Figures A-11 and A-12. The UTD based results in Figures A-11 and A-12 are compared with an independent numerical moment method solution of an integral equation for this line source excited dielectric strip geometry. It is noted from these figures that the total UTD field is continuous at the shadow and reflection boundaries as it should be; furthermore, the very close agreement between the totally independent UTD and moment method solutions is indeed gratifying.

The present UTD solution is in a form which suggests an ansatz for extending the thin dielectric half-plane diffraction coefficient to the case of a moderately thick dielectric half-plane. This extension and the extension to the three-dimensional case can be built up from the two-dimensional solutions.

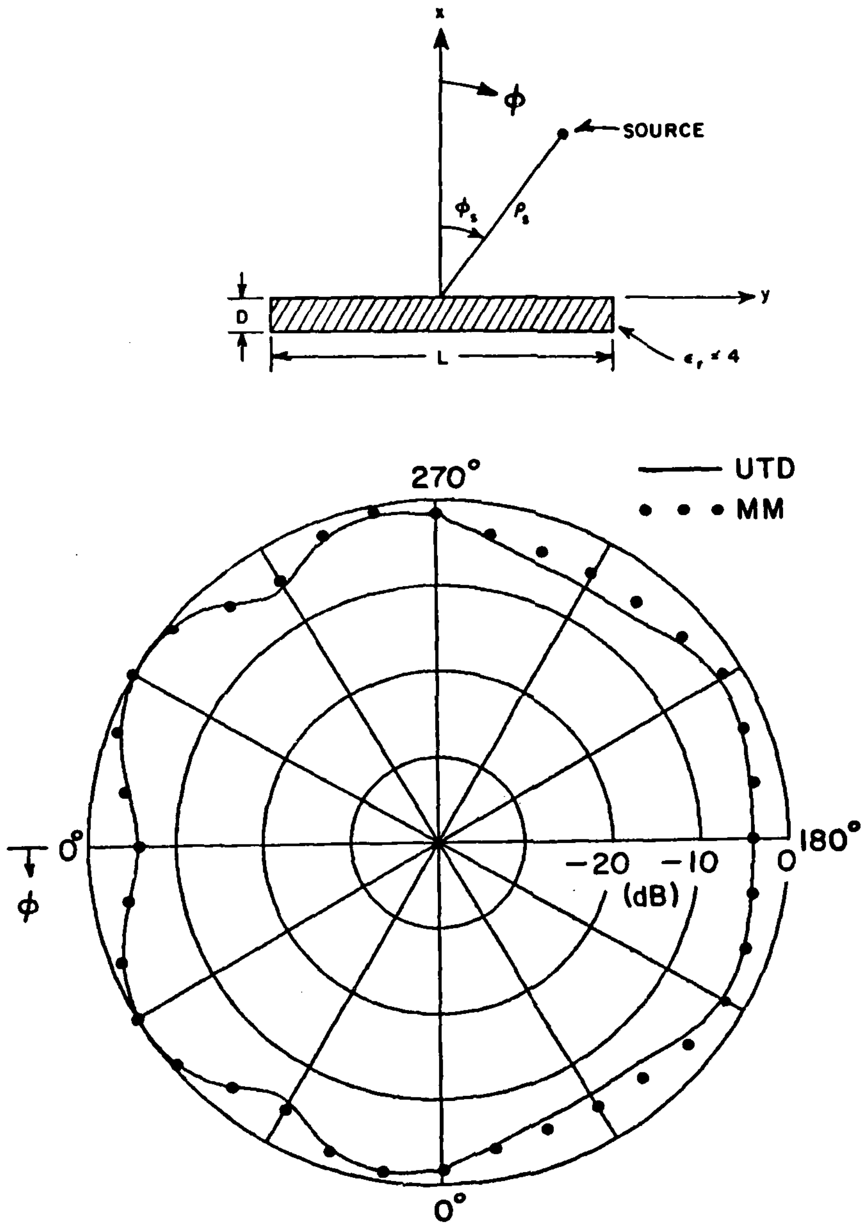

Figure A-11. Electric line source above a thin dielectric strip.

$L = 2\lambda$, $D = 0.05\lambda$, $\phi_S = 0°$, $\rho_S = 1\lambda$.

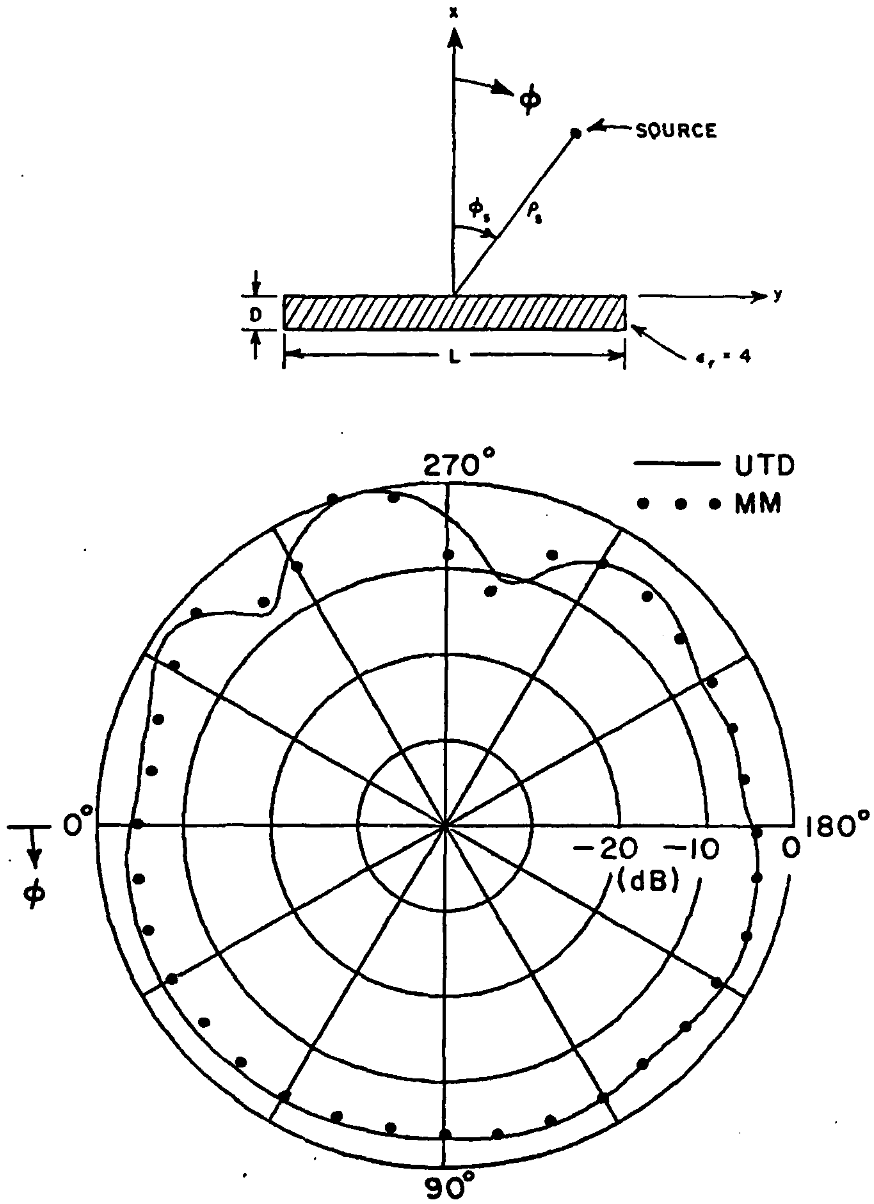

Figure A-12. Electric line source above a thin dielectric strip.

$L = 2\lambda$, $D = 0.05\lambda$, $\phi_S = 60°$, $\rho_S = 2\lambda$.

3. Vertex Diffraction

In many practical antenna problems one encounters situations where an antenna radiates in the presence of finite, planar structures with edges which terminate in a vertex (or corner), e.g., an antenna radiating in the presence of a finite, rectangular ground plane. Also, flat plates with edges are used in the modeling of aircraft wings and vertical or horizontal stabilizers for analyzing on-aircraft antenna patterns. In the above problems, the antenna pattern is affected by the diffraction of electromagnetic waves not only by the edges but also by the vertices or corners. A major effort in the analysis of vertex diffraction is planned as described in the paragraphs to follow.

A formally exact eigenfunction solution has been obtained earlier at the ElectroScience Laboratory [7]; however, this solution is not given in terms of simple functions and it is therefore quite difficult to implement in the GTD format. Nevertheless, this convergent solution is of great value in numerically checking very approximate high-frequency solutions obtained by asymptotic methods. More will be said about this later in this section.

Approximate, asymptotic high-frequency solutions to the vertex or corner diffraction problem have been presented for the acoustic case [8,9]. While these solutions constitute a first step in obtaining useful solutions, they are not uniform in that the vertex diffraction coefficient obtained is not valid along the vertex and edge shadow boundaries where the edge and vertex diffracted fields assume their greatest magnitude and importance. Some initial work on vertex diffraction recently pursued at the ElectroScience Laboratory has led to a simple, approximate vertex diffraction coefficient which appears to work reasonably well for certain cases. However, this result has been obtained heruistically, and it needs to be improved in order for it to be useful in the general situations encountered in practice; nevertheless, this diffraction coefficient offers some clues for constructing the more refined and useful vertex diffraction coefficient, which we expect to obtain from asymptotic analysis.

The canonical geometry presented in Figure A-13 locally models a typical vertex in a finite, planar, perfectly-conducting surface. In general, a vertex in a planar surface is formed by the intersection of two otherwise smooth, curved edges which constitute two of the other boundaries of the surface. The angle α, shown in Figure A-13, is the internal angle enclosed by the tangents at the vertex to each of the two intersecting curved edges.

The asymptotic high-frequency analysis of electromagnetic vertex diffraction is rather complicated. Vertices not only shadow the incident field, but they also shadow the edge diffraction fields. The shadow boundary of an edge diffracted field is a conical surface whose tip coincides with the vertex and whose axis is an extension of the shadowed edge. The vertex introduces a diffracted ray which penetrates the shadow regions; moreover, the vertex diffracted field must also compensate the discontinuities in the incident and edge diffracted fields at their shadow boundaries. At these boundaries the vertex diffracted field assumes its largest magnitude and, hence, its greatest importance. If the vertex diffracted field is omitted in the GTD solution, then substantial discontinuities connected with the shadowing of the incident

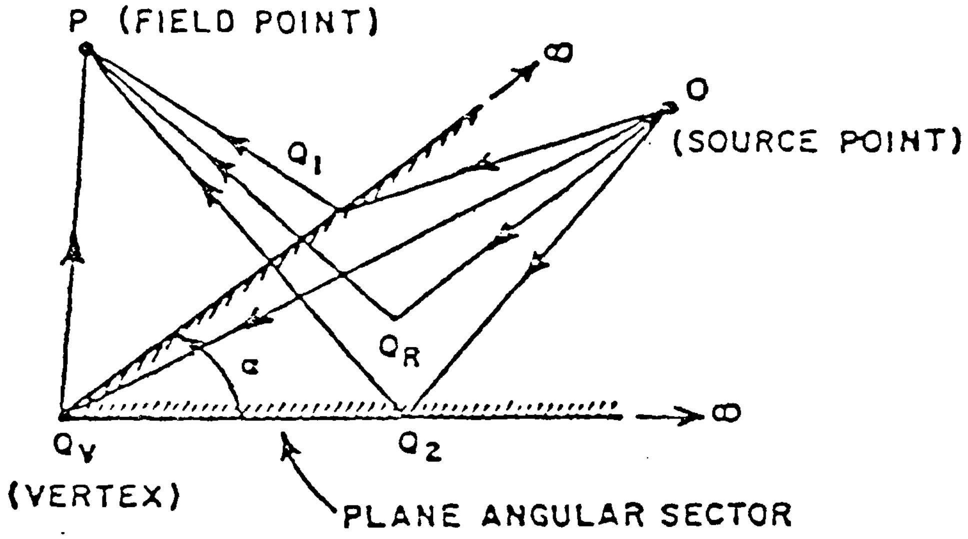

Figure A-13. Various rays associated with the diffraction of waves by a plane angular sector.

and edge diffracted fields may occur in the calculated radiation pattern.

The high frequency solution to this canonical problem may be carried out by asymptotically evaluating an integral representation for the fields scattered by the plane angular sector. The current on the plane angular sector which appears in the integral for the scattered field may be approximated by the local half-plane currents near the edges, the geometrical optics currents in the interior region, and a component near the vertex. The latter component can be expressed as the first few terms of the eigenfunction solution [7] or by an approximate quasi-static solution which is valid near the vertex. The asymptotic evaluation of the integral representation for the scattered field would be based on the method of stationary phase. Three types of critical points shown in Figure A-13 are involved; an interior point O_R associated with the geometrical optics reflected field, edge points O_1 and O_2 associated with the edge diffracted fields, and a critical point at the vertex O_V associated with the vertex diffracted field. The rays associated with these different field contributions also are used to treat the case where there is a confluence of these critical points. It is hoped that the transition function associated with this confluence is reasonably simple, otherwise one must settle for a solution which is partially uniform; i.e., there would be one solution valid in the transition regions of the shadow and reflection boundaries, and a second solution valid outside the transition regions where the critical points are isolated. To be useful, the two solutions must overlap.

As was mentioned earlier, a convergent solution would be valuable in checking the diffraction coefficient obtained by the method of the preceding paragraph. Therefore, it is proposed that the dyadic Green's function for the plane angular sector be determined accurately. It will be seen that this largely reduces to an eigenvalue problem of the Lame' equations.

To find the dyadic Green's function we begin by expanding it in terms of a complete set of vector wave functions which are solutions of the vector wave equation along with the radiation condition and the boundary conditions at the surface of the sector. The vector wave functions are in turn expressed in terms of scalar wave functions which are solutions to the scalar wave equation with the appropriate boundary conditions. Both Neumann and Dirichlet type boundary conditions must be satisfied to yield a complete set of vector wave functions. The final step of the solution involves separating the scalar wave equation in the sphero-conal coordinate system. The resulting separated equations include the spherical Bessel equation and two Lame' equations (one with periodic boundary conditions and the other with nonperiodic ones) which are coupled through the two eigenvalues which are actually the separation constants. It is precisely these eigenvalue pairs which serve as the summation index of the free space dyadic Green's function solution.

The solution is thus ultimately reduced to solving for the eigenvalues and eigenfunctions of the separated Lame' equations. It is then a straightforward procedure to construct the vector wave functions and hence the free space dyadic Green's function. Once this is found, one can proceed to investigate a wide variety of problems because of the versatility and general nature of the Green's function solution.

There is no known closed form solution to the Lame' equations and one is therefore attracted to an infinite series solution. Earlier work used Fourier sine and cosine series representations, but these resulted in the need to solve two simultaneous infinite continued fraction equations for the eigenvalues and eigenvectors. This solution proves to be numerically formidable, and indeed, almost impossible for higher order eigenvalues because of the rapidly varying nature of the continued fractions. More recently, it has been suggested that associated Legendre functions be used as a basis set in one of the Lame' equations. This appears to result in some reduction of the aforementioned difficulties. Still, however, one is faced with some sort of two dimensional search involving complicated simultaneous equations. This recent work suggests that it may be possible to find appropriate sets of basis functions for the solutions to the Lame' equations which would result in a decoupling of the two-dimensional nature of the problem into one that requires solving two one-dimensional problems independently. Alternatively, this decoupling might be achieved by calculating the eigenvalues of the two-dimensional Beltrami operator. These eigenvalues are one of the pair of eigenvalues of the coupled Lame' equations. Efficient procedures for determining these eigenvalues are currently under investigation.

The numerical procedures for the eigenvalues of the plane angular sector problem can be readily generalized to treat the elliptical cone, so that the diffraction by a perfectly-conducting elliptical cone can be examined at a later phase in this study.

4. Finned Cylinders

A high-frequency analysis is being developed for analyzing the back-scatter from a perfectly-conducting finite length circular cylinder with identical planar fins placed equally apart near one of its ends. This configuration is illuminated by an arbitrarily polarized electromagnetic plane wave which is obliquely incident on the cylinders. Away from the nose-on and tail aspects, an approximate solution to this problem can be synthesized from the Uniform GTD (UTD) solutions to two related problems; namely, the backscatter from a finite length circular cylinder without fins, and the backscatter from a two-dimensional circular cylinder with a single fin. The solution to the first problem employs the unliform edge diffraction coefficients given by Kouyoumjian and Pathak [2]. This solution remains valid even within the caustic regions (near nose-on and tail aspects) for the finite cylinder; also, the diffraction from the two ends of the cylinder properly combine to yield a bounded and continuous field for aspects at and near broadside. The other solution for the two-dimensional circular cylinder with a fin also employs the uniform edge diffraction coefficient together with a recently developed uniform solution for the diffraction by a convex cylinder given by Pathak [10]. The total backscattered field would then consist of the UTD fields backscattered by the finite cylinder alone and a "modified" physical optics result for the field backscattered from each of the visible fins. In the latter case, the fin contribution essentially consists of the UTD fin scatter result pertaining to an effective 2-D cylinder with a fin, but modified by a factor that accounts for the 3-D nature of the fin. Thus, the important field interactions between the fins and the cylinder are taken into account in contrast with the previous high frequency treatment of this problem. Calculations of the echo area based on this solution will eventually be compared with measured values. Typically, three or four finned cylinders are being studied in this work. Some preliminary results of this work are presented in Figures A-14, A-15, and A-16 for the case of normal incidence on a circular cylinder with a single fin. Figure A-14 indicates the geometry of the problem; whereas, Figure A-15 indicates the various rays which are employed in the solution of the problem.

It is also of importance and interest to extend this work in the later phases of this study to calculate the echo area for near nose-on or tail aspects. In particular, the nose section of the finite cylinder will also be modified to include a conical shape. For near nose-on and tail aspects, the interactions between the fins and the cylinder would occur within the paraxial region of the cylinder. While the construction of a rigorous asymptotic solution for the paraxial case is not a simple task, some other useful techniques will be considered to analyse this case. Such techniques could include a Kirchhoff type procedure which

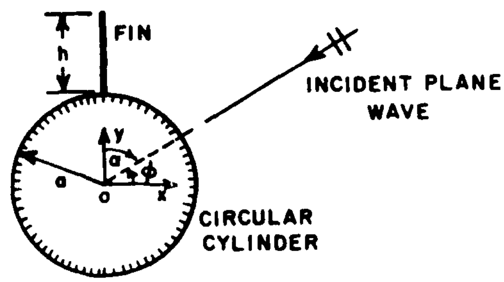

Figure A-14. Plane wave excitation of a circular cylinder with a fin.

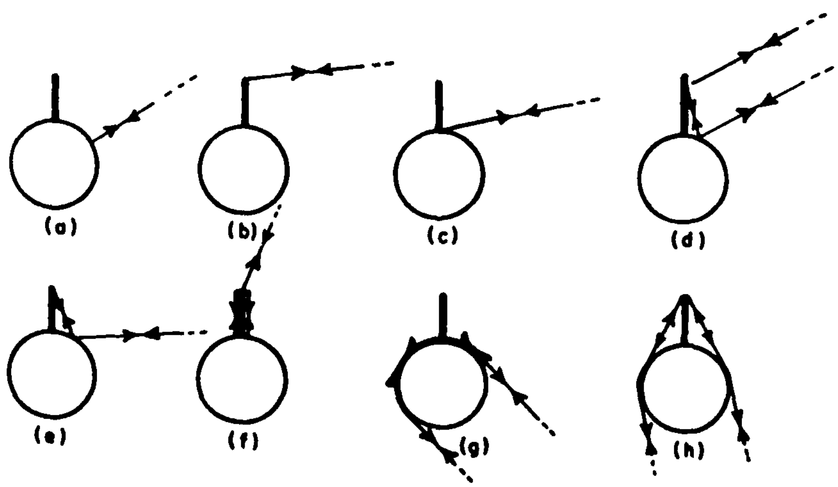

Figure A-15. Dominant rays reflected and diffracted by the fin-cylinder configuration. Additional fin-cylinder ray interactions which may be important if the fin and/or the cylinder are not too large in terms of the wavelength are not shown.

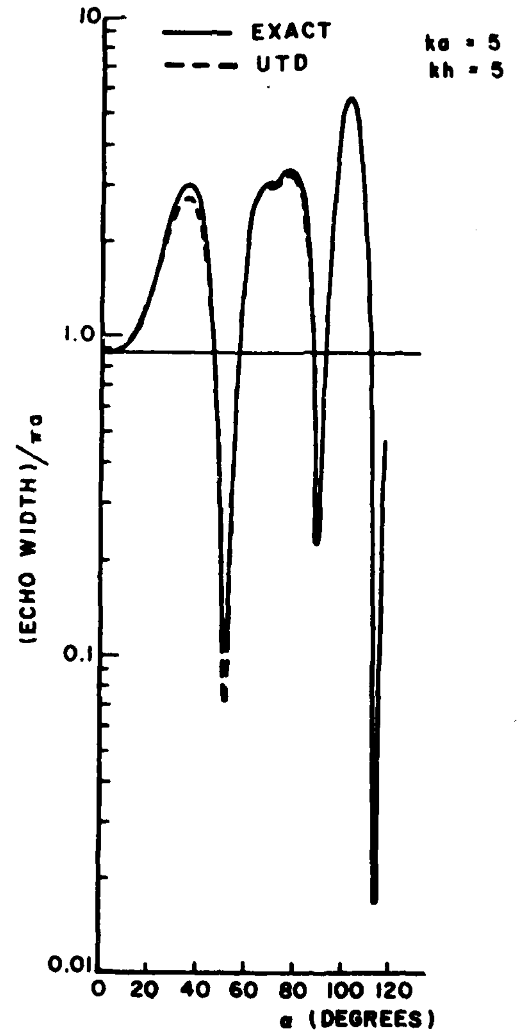

Figure A-16. TE backscattering echo width vs. a for the configuration in Figure A-14.

would employ the surface currents within the paraxial region reported recently by Pathak and Wang, who obtained the surface fields of sources on an arbitrary convex surface (see Section 1a).

5. Caustic Field Analysis

The GTD is a very convenient and accurate procedure for analysing high frequency radiation, scattering, and diffraction problems. However, the GTD suffers from a limitation inherent in ray methods; namely, it cannot be employed directly to evaluate fields at and near focal points or caustics of ray systems. The field at caustics must, therefore, be found from separate considerations [11,12].

In certain problems such as in the diffraction by smooth, closed convex surfaces or by surfaces with a ring-type edge discontinuity, it is possible to employ the GTD indirectly to evaluate the fields in the caustic regions via the equivalent ring current method [13,14]. However, even the equivalent ring current method fails if the incident or reflection shadow boundaries contain a caustic.

The recently developed uniform GTD (or UTD) solution for the scattering and diffraction of waves by a convex surface as described in Section 1a offers clues as to how it may be employed indirectly to obtain the far zone fields in caustic regions where the surface is illuminated by a distant source. In the latter case, the shadow boundary and caustic transition regions tend to overlap. The far zone fields in the near axial direction of a closed surface of revolution illuminated by an axially directed plane wave can be expressed in terms of an equivalent ring current contribution plus a dominant term which may be interpreted as an "effective aperture integral". The latter integral can be evaluated in closed form. In the near zone, where the shadow boundary and caustic directions are sufficiently far apart, only the equivalent ring current contribution remains significant. This solution will be extended in later parts of this study to include more general cases of non-axial incidence and also arbitrary, closed convex surfaces.

Another problem which is also of importance, and which is of a nature somewhat similar to that of the problem of near-axial diffraction by a convex surface of revolution, is the problem of the radiation from open ended waveguides of circular or elliptic cross-sections. These waveguides are commonly used as feeds for reflector type antennas or phased array antennas; furthermore, they are also used as probes for near field measurements. In the circular waveguide case, the circular waveguide mode fields can be decomposed into an equivalent set of ray fields near the edge of the open end of the waveguide. The equivalent-ray system forms a cone about the waveguide axis and these rays diffract from the edge (or rim) at the open end; thus, there is a corresponding shadow and reflection boundary cone (for each waveguide mode) which exists outside the open ended circular waveguide. In addition, the axis (of the waveguide) is a caustic of the rays diffracted from the edge (or rim) at the open end. Thus, the rays diffracted from the edge (or rim) of the open ended waveguide must remain valid across the transition regions associated with the nearby axial caustic direction and the shadow (and reflection) boundary directions. A solution to this problem has been recently obtained in a form which closely resembles the solution for the problem of near-axial diffraction by a convex surface of revolution. This solution will be reported in the near future. While extensions to treat the radiation from open ended elliptic waveguides are not planned, the basic approach should be similar to that employed for the circular waveguide case.

Additional problems of interest which are presently being studied deal with the calculation of the field reflected from a concave surface. In this case, caustics of the reflected rays can occur at some point along the reflected ray path. The field as predicted by ray (geometrical) optics would again not be valid in the caustic regions; in fact, it would be singular at the caustics. It would be useful, therefore, to develop a separate solution which remains valid in the caustic regions via an asymptotic evaluation of the radiation integral for the reflected field. At first, a two dimensional problem would be treated for simplicity, and the currents on a finite concave reflector would be approximated by physical optics. The radiation integral over these currents can then be asymptotically evaluated to yield the field at and near the caustic. Eventually an attempt should be made to arrive at useful expressions for the fields near caustics associated with three dimensional concave reflecting surfaces. The latter problem is of interest in the analysis of scanning reflector antennas and for synthesizing feed distributions for such antennas. It is also of interest in the design of subreflectors. A study of these topics will be continued in the future.

Two other important examples which exhibit interesting caustic effects occur in the problem of radiation and mutual coupling associated with antennas on a smooth convex surface. These problems also will be investigated in the future with a view towards analyzing the caustic region fields; the fields away from caustic have been determined at the present time as described in Section 1a.

6. Time-domain GTD

The development of a time-domain version of the GTD in terms of progressing waves is of value because some of the advantages of the GTD in the frequency domain carry over directly to the transient analysis. For example, the method may be applied to complex shapes which occur in practice and the resulting solution in terms of ray contributions easily can be identified with the radiation mechanisms involved (reflection, edge diffraction, surface diffraction, etc.). These transient solutions may be used to determine the response of objects exposed to EMP or to study problems connected with target identification. Also, it is often possible to test and compare high-frequency solutions more conveniently by inversely transforming them to the time domain.

Recently, time domain edge diffraction coefficients have been obtained so that the early time diffracted fields or induced surface current and charge densities can be calculated directly in the time domain by means of progressing waves. The fields or currents and charges are represented as the sum of a geometrical optics contribution and contributions from rays singly- and doubly-diffracted from the edges. This approach was used to find the early time surface currents and charges on a strip and the early time transient radiation from the end of a parallel plate wave-guide. However, it is also desirable to apply the time domain GTD to scatterers with curved edges, such as circular discs and cylinders. In these cases a caustic may occur on the diffracted ray path, and this in turn results in a more causal expression for the field of the diffracted ray even at distances far from the caustic. Work on the latter problem will go on into the future phases of research on time-domain GTD along with studies to extend time-domain GTD to obtain adequate early- and intermediate-time solutions for transient fields reflected and diffracted from convex surfaces.

Publications and Presentations

1. Articles

Please refer to the section entitled "Accomplishments", which describes the progress to date on the research topics together with the list of publications.

2. Oral Presentations

a. "Near and Far Field Airborne Antenna Pattern Analysis", by P.H. Pathak, W.D. Burnside, N. Wang, and T. Chu; paper presented at the IEE International Conference on Antennas and Propagation which was held at the University of York, U.K., during April 13-16, 1981.

b. "An Asymptotic High Frequency Analysis of the Radiation From Sources on Perfectly-Conducting Structures with an Impedance Surface Patch", by P.H. Pathak and L. Ersoy; paper presented at the IEE International Conference on Antennas and Propagation which was held at the University of York, U.K., during April 13-16, 1981.

c. "High Frequency Scattering by a Thin Dielectric Slab", by W.D. Burnside and P.H. Pathak; paper presented at the IEE International Conference on Antennas and Propagation which was held at the University of York, U.K., during April 13-16, 1981.

d. "Ray Analysis of EM Backscatter from a Jet Intake Configuration", by P.H. Pathak and C.C. Huang; paper presented at the IEEE International Antennas and Propagation Symposium which was held at the Bonaventura Hotel, Los Angeles, California, during June 16-19, 1981.

3. Invited Lectures

"The New Geometrical Theory of Diffraction", presented by R.G. Kouyoumjian at the Courant Institute of Mathematical Sciences, New York University, New York, November 6, 1981.

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B. Hybrid Techniques

Researchers: W.D. Burnside, Research Scientist and Associate Professor (Phone: (614) 422-5747)

P.H. Pathak, Research Scientist and Adjunct Assistant Professor

C. Chuang, Senior Research Associate

Accomplishments

During the current phase of hybrid GTD-MM studies, work was devoted to obtaining a solution of the diffraction coefficient for a curved surface/curved surface junction which has a discontinuity in curvature.

Consider the two-dimensional radiation problem shown in Figure B-1. A line source at P radiates in the presence of a conducting convex cylinder. A high frequency ray formulation of the total radiated field has been obtained by Pathak [1]. For simplicity, assume that the radius of the conducting cylinder is a constant, a. The total field at P_a and P_s are given as follows:

$$U_{\substack{s\\h}}(P_L) \approx U^i_{\substack{s\\h}}(P_L) + U^i_{\substack{s\\h}}(Q_R)\, R_{\substack{s\\h}}\, \frac{e^{-jk\ell}}{\sqrt{\ell}}$$

$$U_{\substack{s\\h}}(P_S) \approx U^i_{\substack{s\\h}}(Q_1)\, T_{\substack{s\\h}}\, \frac{e^{-jks}}{\sqrt{s}} \tag{1}$$

where the subscripts s and h denote the soft and hard cases, the superscript i denotes the direct incident field from the source, and

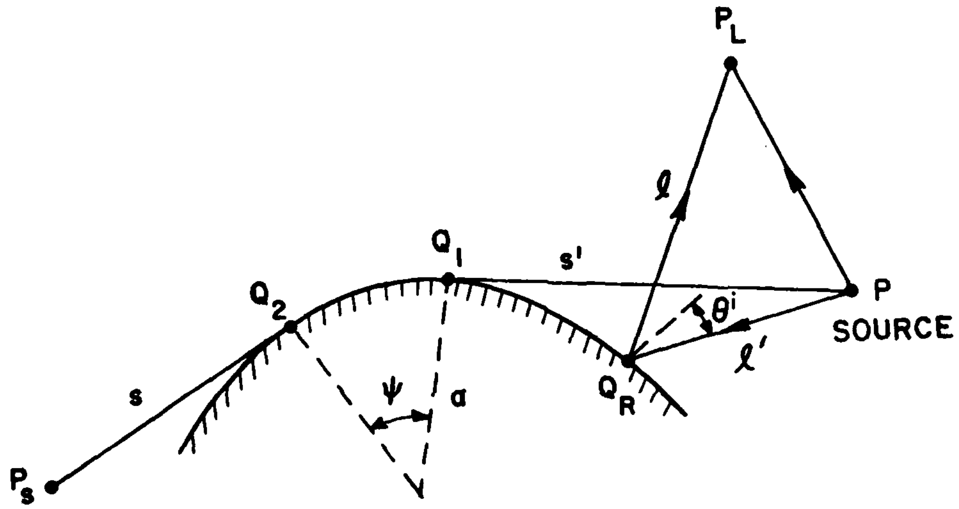

Figure B-1. High frequency radiation of a line source in the presence of a conducting cylinder.

$$R_{\substack{s\\h}} = -e^{-j\pi/4} \left\{(1/2)\sqrt{\frac{L^{\ell}}{\pi X^{\ell}}}\ F(X^{\ell}) + M\sqrt{\frac{2}{k}}\ q^{*}_{\substack{s\\h}}\ (\xi^{\ell})\right\} e^{-j(\xi^{\ell})^{3}/12}$$

$$\bullet \left\{1 + \frac{1}{\left(\frac{1}{\ell} + \frac{1}{\ell'}\right)} \frac{a \cos\theta^{i}}{2}\right\}^{-1/2}$$

$$T_{\substack{s\\h}} = -e^{-j\pi/4} \left\{- (1/2)\sqrt{\frac{L^{d}}{\pi X^{d}}}\ F(X^{d}) + M\sqrt{\frac{2}{k}}\ q^{*}_{\substack{s\\h}}\ (\xi^{d})\right\} e^{-jkt}$$

with

$$M = (ka/2)^{1/3}$$

$$\xi^{\ell} = 2M\cos\theta^{i}$$

$$L^{\ell} = \frac{\ell\ell'}{\ell+\ell'}$$

$$X^{\ell} = \frac{kL^{\ell}(\xi^{\ell})^{2}}{2M^{2}} = 2kL^{\ell}\cos^{2}\theta^{i}$$

$$\xi^{d} = M\psi$$

$$L^{d} = \frac{ss'}{s+s'}$$

$$X^{d} = \frac{kL^{d}(\xi^{d})^{2}}{2M^{2}}$$

$$F(X) = 2j\sqrt{X}\ e^{jX} \int_{\sqrt{X}}^{\infty} e^{-jt^{2}}\ dt$$

$q_{\substack{s\\h}}(\xi)$ = a Pekeris function.

However, if there is a discontinuity in the radius of curvature of the conducting cylinder, an additional ray field must be added to the above formula to yield the total radiated field. As shown in Figure B-2, the radius of curvature of the conducting cylinder changes from a_1 to a_2 at point O. The total field at P_L includes a direct ray, a reflected ray and a diffracted ray due to the discontinuity in the radius of curvature of the conducting cylinder. The direct ray and reflected ray fields are the same as given in (1) with "a" replaced by a_1 or a_2, depending on the radius of curvature of the conducting cylinder at the point of reflection O_R. The reflected ray field is discontinuous across the reflection boundary defined by $\phi = \pi - \phi'$. In order that the total field be continuous everywhere, the diffracted ray field must also be discontinuous across the reflection boundary and the discontinuities in the reflected ray and diffracted ray fields must exactly compensate each other. A diffracted ray field has the format

$$U^d(P_L) \sim U^i(O)\, D_{\substack{s\\h}} \frac{e^{-jk\rho}}{\rho} \qquad (2)$$

where $D_{\substack{s\\h}}$ is defined as the diffraction coefficient due to the discontinuity in curvature. An approximate solution of the diffraction coefficient has been obtained as

$$D_{\substack{s\\h}} = \frac{e^{-j\pi/4}}{2\pi k} \frac{C_{\substack{s\\h}}(\xi_1)F(X_1) - C_{\substack{s\\h}}(\xi_2)F(X_2)}{\cos\phi + \cos\phi'}$$

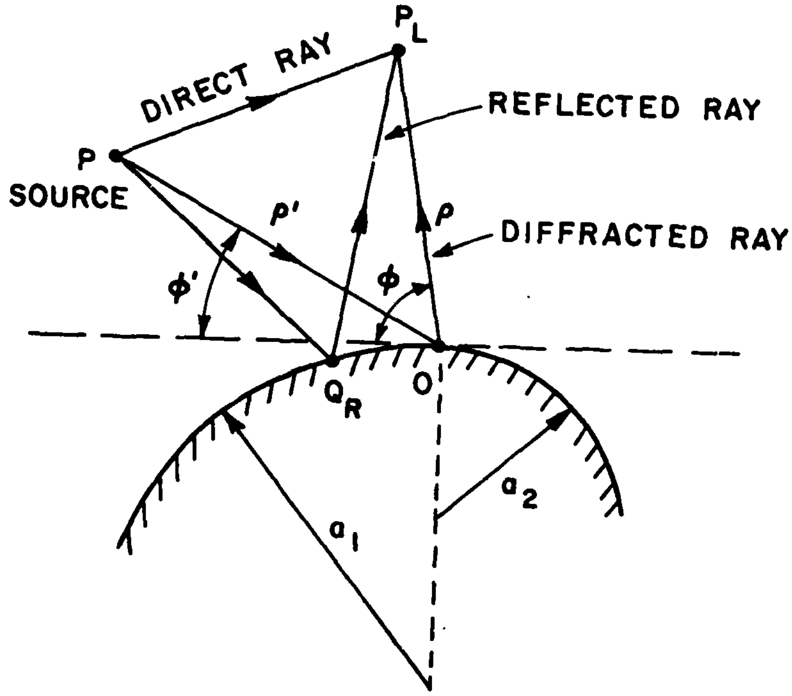

Figure B-2. Diffraction due to curvature discontinuity.

where

$$C_{\substack{s\\h}}\ (\xi_{1,2}) = \sqrt{\frac{2\cos\left(\frac{\phi-\phi'}{2}\right)}{a_{1,2}}}\ \left\{(1/2)\ \frac{L}{\pi X}\ F(X)+M_{1,2}\sqrt{\frac{2}{k}}\ q^{*}_{\substack{s\\h}}\ (\xi_{1,2})\right\}$$

$$\bullet\ e^{-j\pi/4-j(\xi_{1,2})^{3}/12}$$

$$\xi_{1,2} = -2M_{1,2}\cos\left(\frac{\phi-\phi'}{2}\right)$$

$$M_{1,2} = (ka_{1,2}/2)^{1/3}$$

$$L = \frac{\rho\rho'}{\rho+\rho'}$$

$$X = 2kL\cos^{2}\left(\frac{\phi-\phi'}{2}\right)$$

$$X_{1,2} = \frac{ka_{1,2}\ (\cos\phi + \cos\phi')^{2}}{2\ [\sin\phi'(1 + \left[\frac{a_{1,2}}{\rho'}\right]\sin\phi') + \sin\phi(1 + \left[\frac{a_{1,2}}{\rho}\right]\sin\phi)}$$

This diffracted ray field has the desired feature at the boundary of reflection, i.e., that it is discontinuous across the reflection boundary and compensates the discontinuity in the reflected ray field. Furthermore, away from the reflection boundary, the diffraction coefficient is proportional to $(\frac{1}{a_1} - \frac{1}{a_2})$, which agrees with [2]. Although the constant of proportionality is different from that in [2], the diffracted field generally is small away from the reflection boundary where the reflected field dominates. Thus, the slight error can be neglected. Further improvement will be obtained in the future.

Publications

1. C.W. Chuang and W.D. Burnside, "A Diffraction Coefficient for a Cylindrically Truncated Planar Surface", IEEE Trans on Antennas and Propagation, vol. 28, pp. 177-182, March 1980.

2. W.D. Burnside and C.W. Chuang, "An Aperture-Matched Horn Design", accepted for publication in IEEE Trans. on Antennas and Propagation.

3. W.D. Burnside and C.W. Chuang, "Diffraction from Cylindrically Truncated Planar Surface with Application to an Aperture-Matched Horn Design", IEE Antennas and Propagation Conference publication, No. 159, part 1, pp. 367-372, April 1981.

Presentations

"Diffraction from Cylindrically Truncated Planar Surfaces With Application to an Aperture Matched Horn Design", by W.D. Burnside and C.W. Chuang, paper presented at the IEE International Symposium on Antennas and Propagation which was held at the University of York, U.K., during April 13-16, 1981.

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[1] P.H. Pathak, "An Asymptotic Analysis of the Scattering of Plane Waves by a Smooth Convex Cylinder", Radio Science, vol. 14, p. 419, May 1979.

[2] T.B.A. Senior, "The Diffraction Matrix for a Discontinuity in Curvature", IEEE Trans. Ant. and Propagation, vol. 20, p. 326, May 1972.

C. Antenna Studies

Researchers: Dr. E.H. Newman, Research Scientist (Phone: (614) 422-4999)

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P. Alexandropoulos, Graduate Research Associate

M. R. Schrote, Graduate Research Associate

P. Tulyathan, Graduate Research Associate

D.M. Pozar, Graduate Research Associate

Accomplishments

The work on antenna studies encompasses three distinct areas of research:

1. Development of new surface patch moment method solutions.

2. Eigenfunctions of hermitian iterated operators.

3. Eigenfunction expansions of the dyadic Green's function.

This work will now be briefly reviewed.

1. New Surface Patch Moment Method Solutions

Our past work has centered on the moment method solution for structures consisting of perfectly conducting plates and wires. The user oriented computer codes, based upon this work, are capable of analyzing the radiation and scattering (i.e., radar cross-section) from a wide class of antennas on ships, aircraft, land vehicles, etc. The basic philosophy is that the wires are interconnected to form the antenna (i.e., a dipole, loop, etc.), while the plates are interconnected to form the support structure (i.e., a ship, aircraft, etc.). Thus, if one can treat wires and plates, one has the ability to treat a wide variety of wire antennas mounted on or near a highly conducting support structure.

Initially, we developed the techniques [1,2] and an associated user-oriented computer code [3] for analyzing:

1. thin wires
2. rectangular plates
3. plate-to-plate intersections
4. wire-to-plate intersections at least 0.1λ from an edge
5. open or closed surfaces

The code can compute currents, impedance, efficiency, far-zone radiation patterns, and radar cross-section (back or bistatic scattering).

While the existing code is a very powerful and general purpose tool, it has two shortcomings which limit it's generality. First, it can not treat wires attached closer than about 0.1λ from a plate edge. Second, the plates must be rectangular. Thus, it would be difficult to model the swept wing of an aircraft or the pointed bow of a ship. We have developed fundamental solutions to both of these problems [4-7], although these techniques at present have not been integrated into a general purposed user-oriented code.

Our past work has dealt solely with perfectly conducting plates. Our present and future work deals with plates of finite conductivity. The finite conductivity of the plates is modeled via a surface impedance, including the case where the surface impedance of the top surface is different from that of the bottom surface of the plate. The techniques will permit one to analyze such problems as the losses in finitely conducting plates, or an absorbitive coating on one or both sides of a plate. Such coatings can significantly alter the radiation and scattering from the structure.

To treat open finitely conducting surfaces, it is essential to know how the current distributes between the top and bottom surfaces of the plate. This is the initial problem we have been treating before the finitely conducting plates can be treated. Very briefly, one can compute the sum current, i.e., the sum of the currents on the top and bottom surfaces of the plate by solving an electric field integral equation. One can compute the difference current, i.e., the difference between the top and bottom currents, using a magnetic field integral equation. Once the sum and difference currents are known it is straight-forward to compute the top and bottom currents. Figure C-1 shows a 2λ square plate in the xz plane. A $\hat{z}$ polarized plane wave hits the plate from the broadside direction. Figure C-1 shows the sum, difference, top, and bottom currents (normalized to the physical optics current) along the line $x=0$, $0 \leq z \leq 2\lambda$. Note that the difference current is constant and equal to the physical optics current. Also note that the top (illuminated

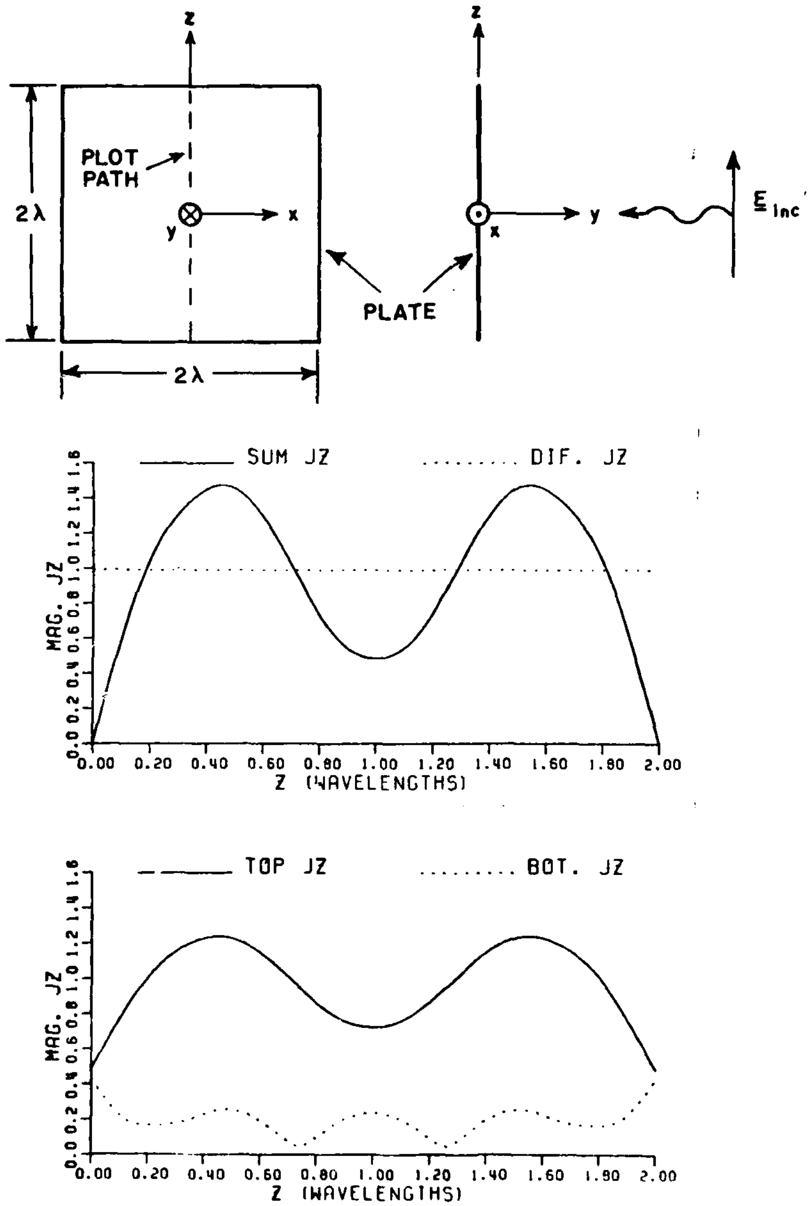

Figure C-1. Currents on a 2λ square plate, normalized to 2|Hinc|, i.e., the physical optics current.

side) current exceeds the bottom (shadowed side) current. However, the bottom current is not negligible.

While computing the top and bottom currents on a perfectly conducting plate is an interesting theoretical problem, it has limited practical use. Thus, it must be emphasized that it is being done as a first step in the solution of finitely conducting plates. The ability to treat finitely conducting plates is a problem of great practical importance, especially with the recent emphasis on the control of the radar cross-section of military objects.

2. Eigenfunctions of Hermitian Iterated Operators

Problems of analysis and synthesis of radiating systems require appropriate functions in which to expand a source distribution and the associated radiated field. To be most useful it is desirable that such functions be suitable for source and field representations simultaneously, that they be complete and that they be orthogonal in some sense over both the source and field region of interest. In the familiar case when the regions of the source and the field coincide with coordinate surfaces or coordinate systems in which the Helmholtz equation is separable, the corresponding eigenfunction representation is valid for both the source and the field.

We have considered the general case where the region of observation does not necessarily coincide with the source region, resulting in orthogonal properties over more general regions than the body surface and the sphere at infinity. An investigation of the validity of Parseval's relation for a more general operator equation than a Fourier transform leads us to an eigenvalue equation of the Hermitian iterated operator, whose solutions shall be called eigensources and the radiated fields of which shall be called eigenfields. An eigensource and an associated eigenfield each satisfies an orthogonality property simultaneously but, in general, over different regions of space. The sets of eigensources and eigenfields can then be used as convenient basis functions with which to solve various problems systematically.

The method has been applied to the optimization of an array under given constraints and for the determination of aperture distributions transferring maximum power to a second aperture. In the latter case, the eigenfunctions arising from the present theory are shown to be the prolate spheroidal functions. In the case where the eigenequation is developed from a current source flowing on a closed surface and the component of the corresponding electric field tangential to the same surface, we are led to eigencurrents and eigenfields which differ from characteristic modes (which involve the same two quantities); whereas a characteristic current and a characteristic field display differing amplitude distributions but maintain a constant phase relationship over the surface, the eigencurrents and eigenfields introduced here display similar amplitude distributions but maintain a complex conjugate phase relationship over the surface. Only when the surface corresponds to a coordinate of the coordinate systems where separability applies do the characteristic functions and the eigenfunctions of the Hermitian iterated operator coalesce to become one and the same such as in the case of the circular conducting cylinder and conducting sphere.

During the past interim, four papers were written for publication [8-11].

3. Eigenfunction Expansion of the Dyadic Green's Function

We have studied a simple method for obtaining the complete eigenfunction expansion of the electric and magnetic fields, $\overline{E}$ and $\overline{H}$, respectively, which are produced by a time harmonic electric point current source that may radiate in the presence of boundaries. As a result of the point source excitation, this expansion of $\overline{E}$ and $\overline{H}$ automatically yields the complete eigenfunction expansion of the corresponding electric and magnetic dyadic Green's functions, $\overline{\overline{G}}_e$ and $\overline{\overline{G}}_m$, respectively. As a first step in this method, the $\overline{E}$ field which is valid everyplace outside the source point is constructed in terms of only the solenoidal eigenfunctions via well known techniques. This solenoidal expansion denoted by $\overline{E}'$ also directly yields the complete eigenfunction expansion of $\overline{H}$, and hence of $\overline{\overline{G}}_m$. It is shown in a general fashion that the delta function correction to $\overline{E}'$ which is necessary for obtaining the complete eigenfunction expansion of $\overline{E}$ or $\overline{\overline{G}}_e$ (that remains valid at the source point) is directly available from the relation governing the discontinuity in $\overline{H}$ across the source point, without having to know $\overline{H}$ (and $\overline{E}'$) explicitly, if one employs an elementary result from distribution theory. The method has been applied to finding $\overline{\overline{G}}_e$ and $\overline{\overline{G}}_m$ for some typical interior (waveguide and cavity) and exterior electromagnetic problems.

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[8] R.J. Garbacz and D.M. Pozar, "Antenna Shape Synthesis Using Characteristic Modes", accepted for publication IEEE Trans. on Antennas and Propagation.

[9] N. Inagaki and R.J. Garbacz, "Eigenfunctions of Hermitian Iterated Operators with Application to Discrete and Continuous Radiating Systems", submitted after revision for review to the IEEE Trans. on Antennas and Propagation.

[10] N. Inagaki and R.J. Garbacz, "Generalized Eigenfunctions of Hermitian Iterated Operators and Eigencurrents and Fields of Perfectly Conducting Bodies", submitted after revision for review to the IEEE Trans. on Antennas and Propagation.

[11] N. Inagaki and R.J. Garbacz, "A Numerical Method of Obtaining Stable Solutions to Scattering by Conducting and Dielectric-Rectangular Cylinders", to be submitted to IEEE Trans. of Antennas and Propagation Society.

D. Time Domain Studies

Researchers: D.L. Moffatt, Associate Professor (Phone: (614) 422-5749)

E.M. Kennaugh, Professor Emeritus

J.S. Bagby, Graduate Research Associate

Introduction

The general goals of our reserach in the time domain have been detailed previously [1] and will not be repeated here. Briefly, the application of time domain concepts and methods to vector and scalar radiation and scattering problems yields tremendous diagnostic and interpretive insight. We seek to exploit this insight for the improved detection and recognition of a signal or signals in active radar and other applications. The integration of all available reliable measured or calculated radiation or scattering data for an object into a single set of real time-dependent waveforms which uniquely sum up the characteristics (electromagnetic or scalar) of the object at all frequencies and for all excitation waveforms describes the impulse response concept. A natural consequence of the impulse response viewpoint was the suggestion, in 1965 [2], that an approximate lumped parameter model of the scattering characteristics of an object was feasible. The complex natural resonances of spherical and prolate spheroidal objects were exploited by Hill [3] in 1971 in a prediction-correlation procedure for improved detection and target recognition. Since that time much of our research effort has been directed toward improved techniques for finding the complex natural resonances of additional classes of object shape and toward an optimization of the excitation waveform for object recognition. One such waveform, the K-pulse, was formally described by Kennaugh in a recent publication [4], although the basic idea was detailed much earlier [5]. The existence of the K-pulse, which has the essential property of duration or memory for distributed parameter systems, means the K-pulse cannot be correctly modeled by the SEM expansions currently in vogue [4]. It appears that there is not complete agreement on this point among SEM advocates.

Accomplishments

It is felt that the publications and presentations listed under Publications and Presentations clearly demonstrate that our research is significant, of interest to the scientific community, and is being widely disseminated.

Perhaps the single most significant new development has been the formal definition and illustration of the K-pulse and its resulting commentary on SEM expansions. It should be noted that these results have absolutely no bearing on our established method of target recognition using dominant complex natural resonances and prediction-correlation processing. That is, the K-pulse may be an improved approach to object recognition for certain applications but it does not negate the earlier method.

1. Natural Resonances, Surface Waves and Geometrical Procedures

The K-pulse concept provides a means of relating surface waves on a structure to the complex natural resonances of the structure. Examples have been given for the conducting sphere, circular cylinder, prolate spheroid and a thin straight wire. A recent thesis by Bagby [5] has extended this concept to various wire configurations such as wire crosses, circular loops and straight bent wires. Procedures have also been developed for the circular disk and the elliptic cylinder. A report based partially on the above thesis is in preparation. For wire geometries, improved estimates of the junction transfer functions and end coupling are being studied. For solid objects there are, in some cases, numerous geodesic paths which must be considered. Some additional research is needed to at least partially improve techniques for selecting those paths of importance from a natural resonance viewpoint.

2. The Circular Disk

The thin circular disk is an attractive object for the development of the K-pulse. First, the object has edges, a case which has not yet been handled. Second, exact far zone scattering results for the disk are available. It has been found that for broadside incidence excellent rational function fits of the scattering function can be obtained which hold up to disk circumferences of five wavelengths. Similar results for other aspects and two principal polarizations should permit good complex natural frequency estimates which can then be compared to the resonances obtained using GTD and a geometrical procedure. Estimates of the K-pulse for the disk would then extend the concept to a new class of target.

3. Transient Currents on a Spherical Scatterer

A report is in preparation on the transient currents induced on a spherical scatterer when illuminated by a plane wave with "shock-type" time dependence. A solution of the spherical scattering problem is not new, or course, but the transient current waveforms and more particularly the simple corrections needed to improve the physical optics approximation are new. Such corrections are important because many solutions to the inverse scattering problem start with the physical optics estimate. Transient waveforms of the exact minus the physical optics estimate, vividly illustrate precisely how the approximation is failing in the "lit" region of the sphere. These difference waveforms also suggest the form of the necessary correction.

4. Duct Configurations

Analytical studies of the electromagnetic scattering by open and truncated circular waveguides initiated and reported on this program [1,6], are presently being pursued on another contract*. In particular, approximate time domain models for the impulse response waveforms are being studied. It is anticipated that this work will not be completed in so far as time domain models, particularly for non-circular ducts and realistic internal structures, are concerned. It is still intended to complete the time domain aspects of these studies but the research has been deferred pending completion of the other contract*.

*Project 712661, prepared under contract F19628-80-C-0056 for Department of the Air Force, Electronic Systems Division, Air Force Systems Command, Hanscom Air Force Base, Massachusetts.

5. Uniform Methods for K-Pulse Estimation

There are two general methods which have been used to estimate the K-pulse for a linear system, scatterer or radiator. The first method analyzes the signal propagation over a closed path, using the net distortion and attenuation to predict complex oscillation frequencies or poles associated with the path. These poles are used to estimate a K-pulse as the finite-duration waveform whose transform zeros coincide with the given pole string. The uniform estimation of an entire function with specified zeros, or more directly the inverse transform or pulse function, has been investigated. Thus far, methods for direct estimation have been successful when the pulse is bounded at all but a finite set of points. We are presently investigating the case in which one or more singularities or known form arise at the endpoints of the pulse interval.

A second method for K-pulse estimation models the propagation path by a non-uniform transmission line. Treating the non-uniform line as a discrete combination of homogeneous sections, the K-pulse of the system is derived as a combination of finite pulse trains, tending in the limit to a sampled estimate of the continuous K-pulse. This method has been successfully applied to transmission lines with varying shunt or series resistive loadings and to lines representing dielectric panels with non-uniform dielectric. A report, "The K-Pulse of Non-uniform Lines", describing the estimation of K-pulses for non-uniform lines is in preparations. Some of the results of this work have already been published [4].

Publications and Presentations

D.L. Moffatt, J.D. Young, A.A. Ksienski, H.C. Lin, and C.M. Rhoads, "Transient Response Characteristics in Identification and Imaging", IEEE Trans. on Antennas and Propagation, Vol. AP-29, No. 2, March 1981. Invited.

D.L. Moffatt, "Ramp Response Radar Imagery Spectral Content", IEEE Trans. on Antennas and Propagation, Vol. AP-29, No. 2, March 1981.

E.M. Kennaugh, "The K-Pulse Concept", IEEE Trans. on Antennas and Propagation, Vol. AP-29, No. 2, March 1981.

L.C. Chan, D.L. Moffatt, and L. Peters, Jr., "Improved Performance of a Subsurface Radar Target Identification System Through Antenna Design", IEEE Trans. on Antennas and Propagation, Vol. AP-29, No. 2, March 1981. Invited.

L.C. Chan, D.L. Moffatt, and L. Peters, Jr., "Subsurface Radar Target Imaging Estimates", IEEE Trans. on Antennas and Propagation, Vol. AP-29, No. 2, March 1981.

E.M. Kennaugh, "Polarization Dependence of RCS - a Geometrical Interpretation", IEEE Trans. on Antennas and Propagation, Vol. AP-29, No. 2, March 1981.

E.M. Kennaugh, "Opening Remarks", IEEE Trans. on Antennas and Propagation, Vol. AP-29, No. 2, March 1981. Invited.

Three additional papers have been accepted for publication:

E.M. Kennaugh and D.L. Moffatt, Comments on "Impulse Response of a Conducting Sphere Based on Singularity Expansion Method", accepted for publication in the Proceedings of the IEEE.

D.L. Moffatt and C.M. Rhoads, "Radar Identification of Naval Vessels", accepted for publication in the IEEE Transactions on Aerospace and Electronic Systems.

D.B. Hodge, "Electromagnetic Scattering by a Circular Disc", accepted for publication in the IEEE Trans. on Antennas and Propagation.

A shortened version of the paper

T.W. Johnson and D.L. Moffatt, "Electromagnetic Scattering by an Open Circular Waveguide",

has been resubmitted to Radio Science.

Two oral papers were presented:

T.W. Johnson and D.L. Moffatt, "Electromagnetic Scattering by an Open Circular Waveguide", presented at the National Radio Science Meeting USNC/URSI, Los Angeles, June 1981.

E.M. Kennaugh, "Canonical Electromagnetic Response Waveforms and Their Estimation", XXth General Assembly of the International Union of Radio Science, Washington D.C., August 1981.

Two additional oral papers

D.L. Moffatt and J.S. Bagby, "Approximate Characteristic Equations for Simple Structures", and

D.L. Moffatt and Chun-Yue Lai, "Electromagnetic Scattering by Loaded Open Circular Waveguides",

have been accepted for presentation at the National Radio Science Meeting at Boulder in January, 1982.

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September 1970, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Contract F19628-70-C-0125 for Air Force Systems Command, Hanscom Field, Bedford, Massachusetts.

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[5] E.M. Kennaugh and J.H. Richmond, "Generalized Aperiodic Excitation in Transient Field Problems", presented at USNC/URSI Spring meeting, Washington, D.C., April 1972.

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E. Transient Signature Measurements of Radar Targets for Inverse Scattering Research

Researchers: J.D. Young, Research Scientist (Phone: (614) 422-6657)
E.K. Walton, Senior Research Associate
W. Leeper, Graduate Research Associate

Accomplishments

1. Introduction and Background

The use of transient response scattering signatures in target identification and inverse scattering research has been the basis of several important research efforts in the past twenty years. This work has been well summarized in the IEEE special issue of the Transactions on Antennas and Propagation which appeared in March 1981. Measurements of transient signature data are tedious and time consuming, but they are a necessary part of such research. Measured data serve to confirm the accuracy of advanced analysis techniques and to obtain new results for identification studies on particular targets which are too complex to obtain computed scattering data.

A technique for making free-space measurements of target transient signatures has been developed and utilized at the Ohio State University ElectroScience Laboratory. Results of sufficient accuracy for target identification and imaging, as well as a description of the measurement technique, have been obtained [1,2,3].

For the 1980-1981 JSEP program, it was proposed that this measurement system be improved and more accurate transient response data vs. polarization be obtained for the following set of simple metallic shapes:

1. Sphere (reference)
2. 2:1 Right circular cylinder
3. 2:1 Right circular cylinder with one spherical cap
4. 2:1 oblate spheroid
5. 4:2:1 ellipsoid.

The above data were intended to permit analysis for the first time on the *transient polarization matrix of scattering objects.*

2. Scattering Range Improvements

Several measurement range improvements were developed and tested in preparation for the data taking. The sensing antenna pair were remounted in a coaxial arrangement for measurement of true backscattering (as opposed to the 12° bistatic angle of previous measurements). With proper adjustment, isolation of better than 40 dB over the band from 1 to 12 GHz was obtained. A computer-controlled positioning apparatus was modified to accommodate the target models. Since two sizes of models were used, this involved positioning at different distances from the sensing antennas so that comparable signal-to-noise performance could be obtained on large and small models. A new technique for evaluating the accuracy of the measurement system was developed [4]. Finally, computer software was improved to speed up the measurement and make the acqusition, labeling, and organization of the large bulk of measured data more convenient.

3. Target Construction

Matched pairs of models with 8:1 size ratios were machined from aluminum for each shape. The largest model (sphere-capped cylinder) is 15" long by 6" diameter. Surface smoothness of <0.01λ at 12 GHz was achieved. A problem arose with the machining of the 4:2:1 ellipsoid. Use of a three axis milling machine was extensively investigated. However, since the weight of the resulting solid aluminum model is a problem, it was decided to manufacture a wood target which would then receive a highly conductive silver plating. Unfortunately, this was not completed by the end of the effort. Measurements of the ellipsoid are now projected for early in the 1981-82 program.

4. Measured Results

Figures E-1 through E-6 show measured vs. calculated sphere backscattered fields from 1 to 8 GHz, and measured data for the sphere-capped cylinder also. Final data conversion is now being accomplished on all data, so that they may be published and made available on floppy disks to other users.

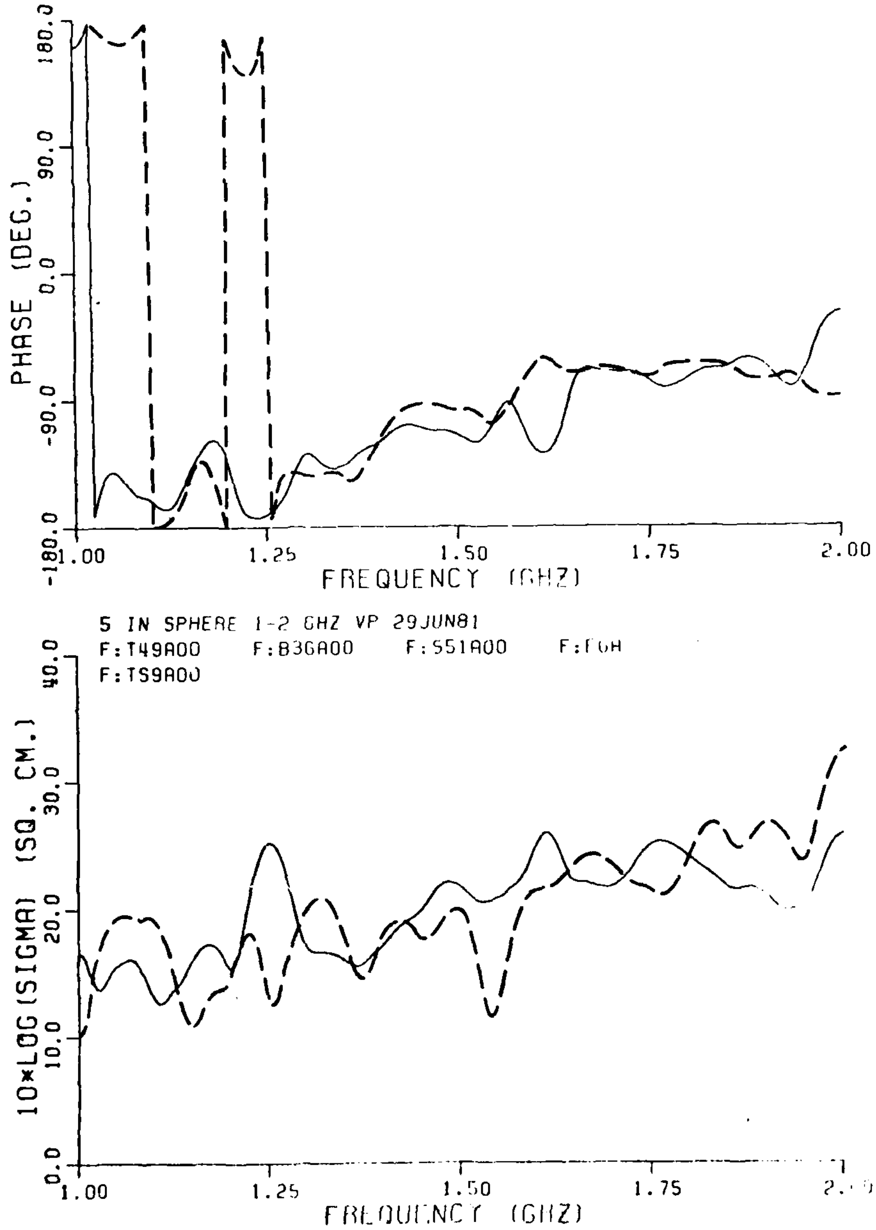

Figure F-1. 5 inch sphere complex backscattered response 1-2 GHz.

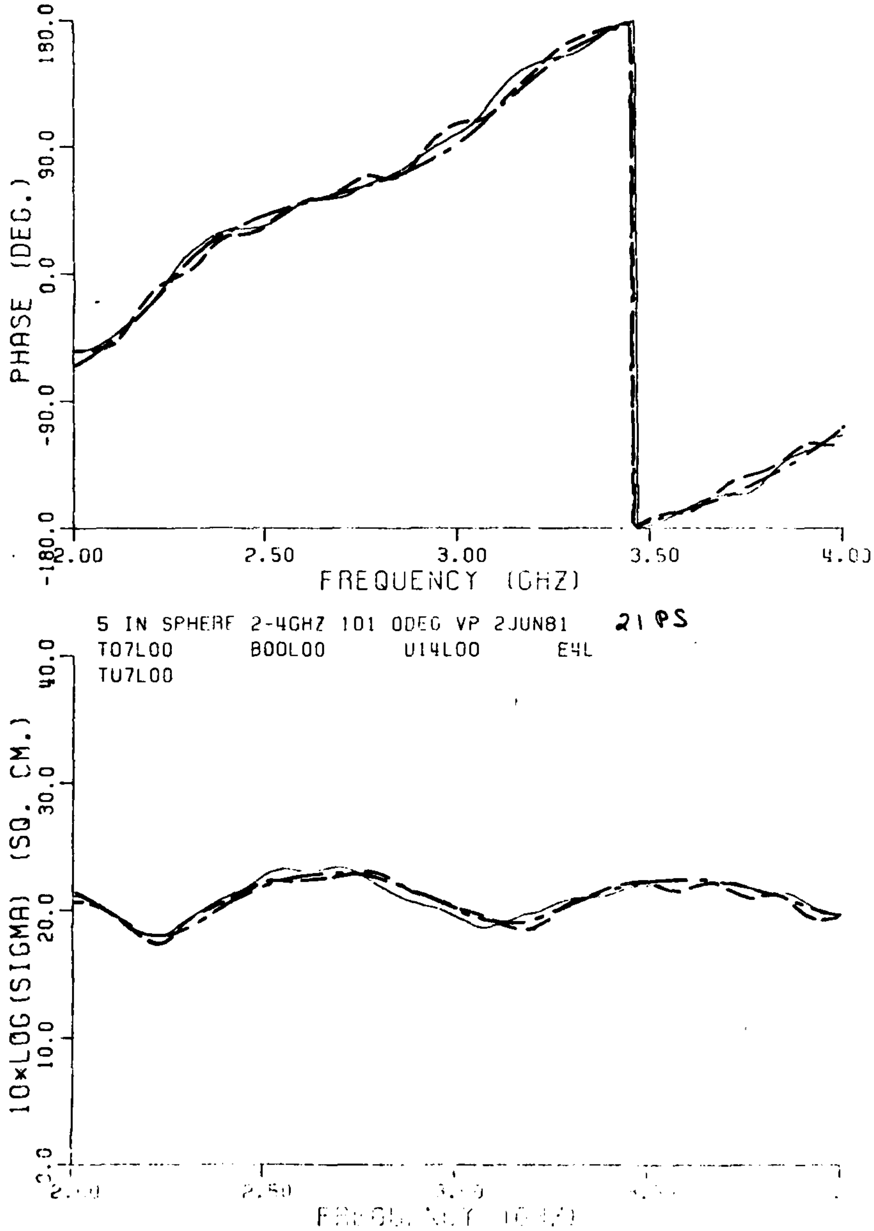

Figure E-2. 5 inch sphere complex backscattered response 2-4 GHz.

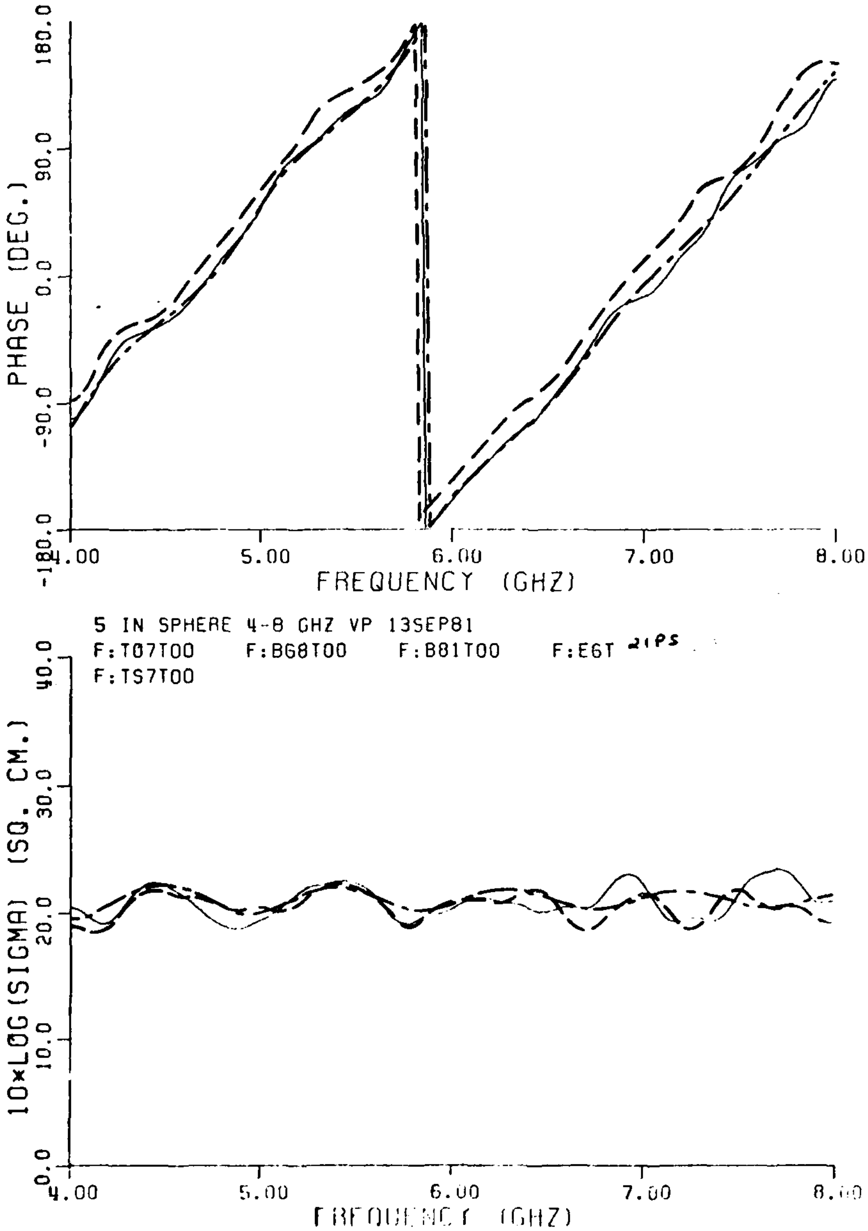

Figure F-3. 5 inch sphere complex backscattered response 4-8 GHz.

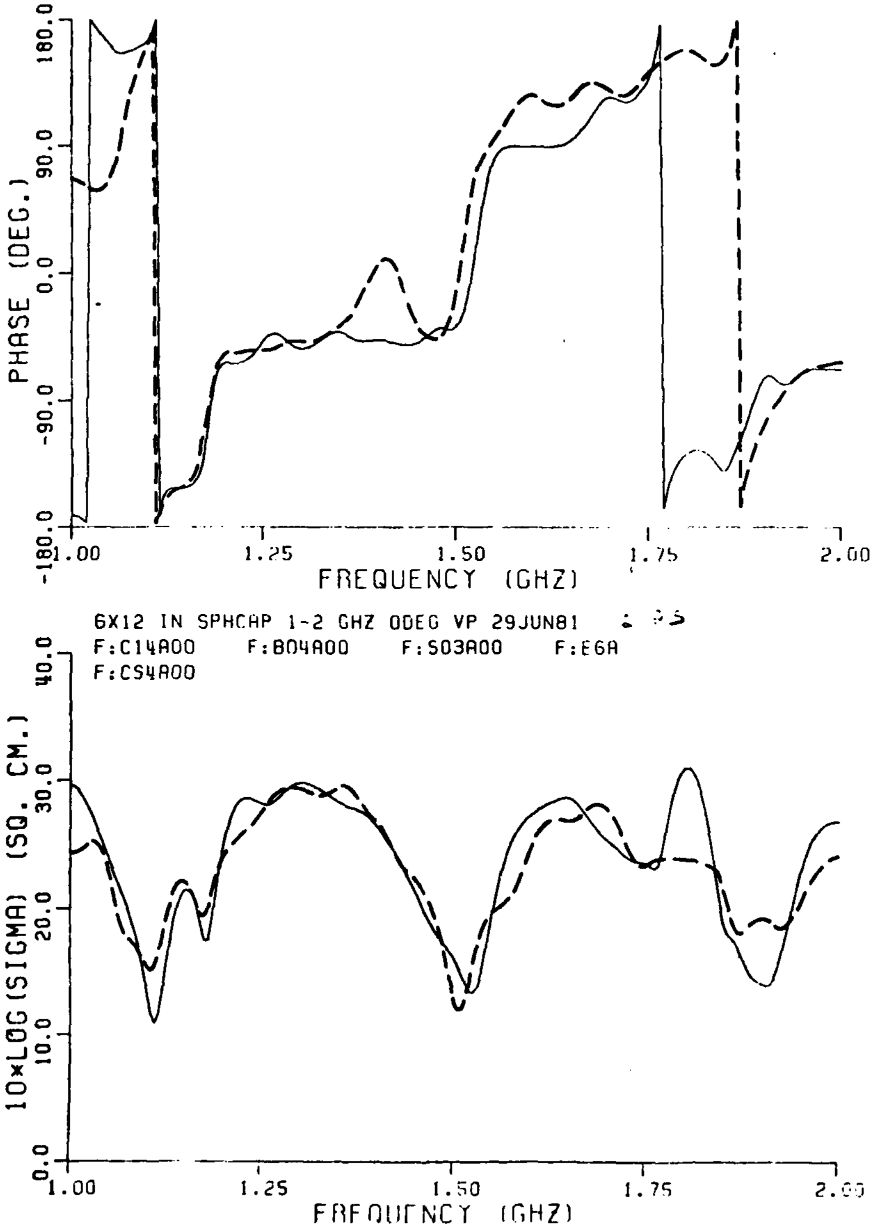

Figure E-4. Sphere-capped cylinder complex backscattered response at nose-on incidence, 1-2 GHz.

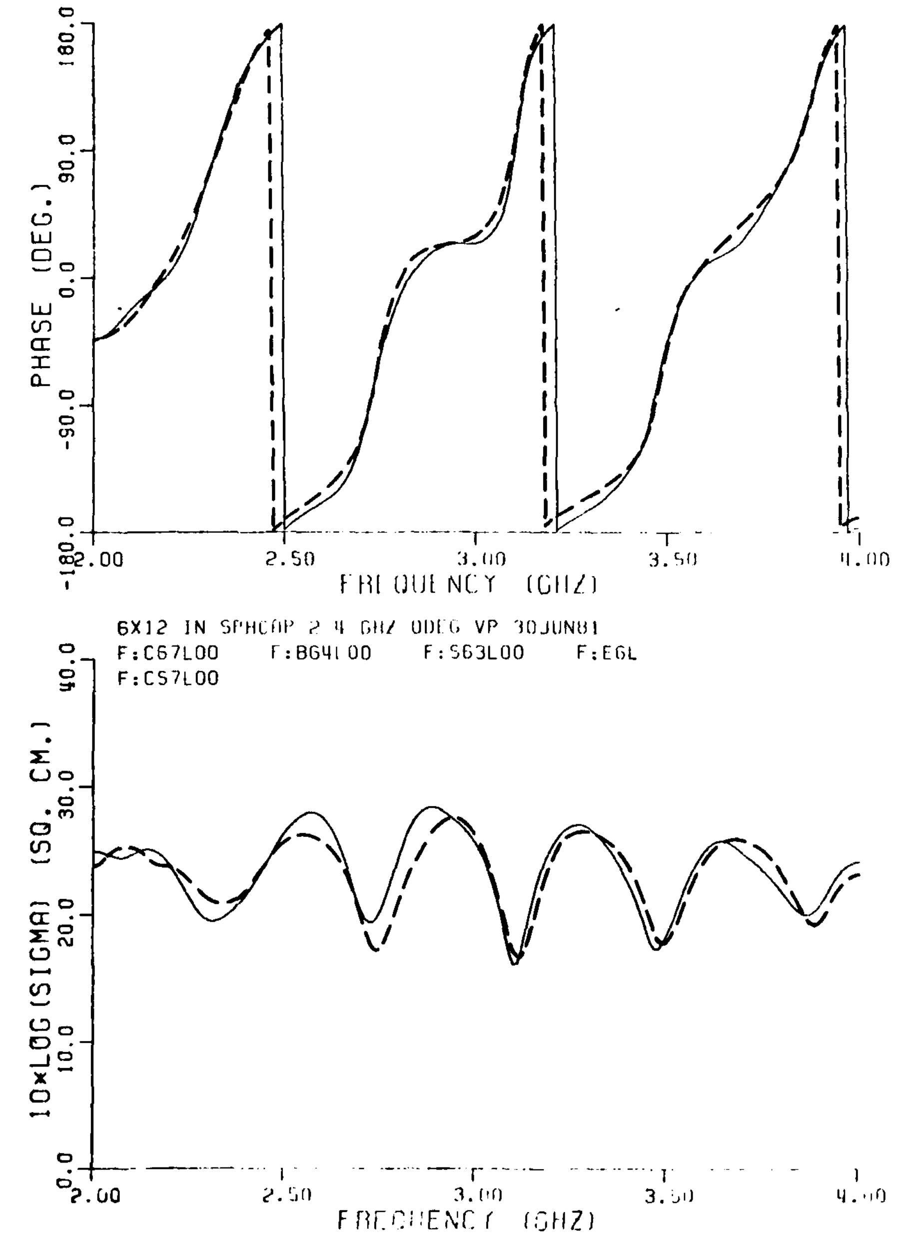

Figure E-5. Sphere-capped cylinder complex backscattered response at nose-on incidence, 2-4 GHz.

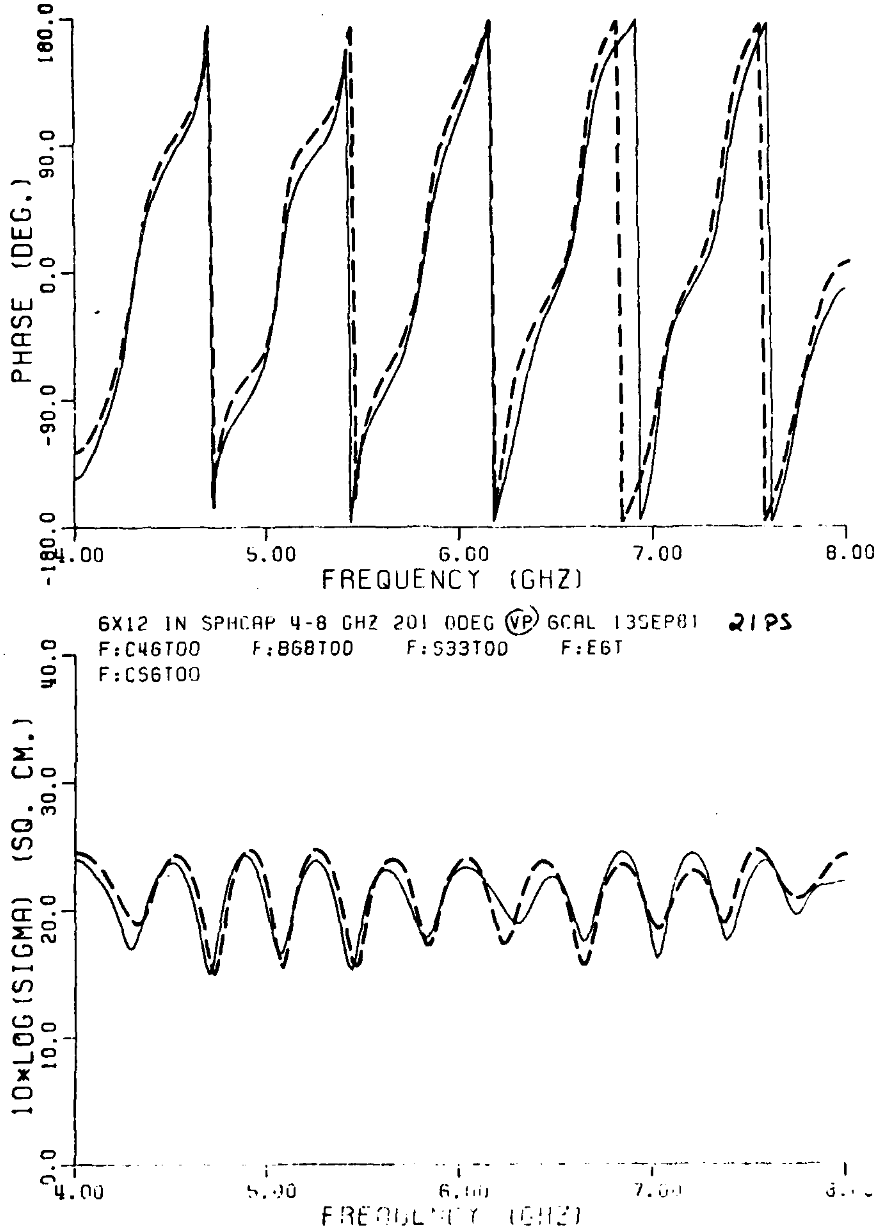

Figure E-6. Sphere-capped cylinder complex backscattered response at nose-on incidence, 4-8 GHz.

5. Swept Frequency System Adaptation to Cross Polarized Measurements

a. Calibration target

The swept frequency system measures the return of target and background, subtracts out the background, and references the raw result to the measured return of a calibration target with a known, exact spectrum. For the H-H and V-V polarized measurements, the natural calibration target is a sphere. The phasor manipulation is:

$$[(\text{TARGET} + \text{BKGRND}) - \text{BKGRND}] * \frac{\text{EXACT SPHERE}}{(\text{CALIBRATION SPHERE} - \text{BKGRND})}$$

In order to adapt this system to cross polarized measurements it was necessary to find a suitable replacement for the calibration sphere. The desired characteristics of the cross polarized calibration target are (in order of priority):

1. An available, exact cross polarized RCS
2. As broadband (non-resonant) as possible in amplitude and phase
3. As high a backscattered signal as possible
4. Fit physically within the uniform field of the horn/dish radar system.

The possible calibration targets considered were:

1. a wire
2. a disc, edge-on
3. a thin strip, edge-on

The wire and the disc were considered too resonant to be a suitable reference. (See T.B.A. Senior, E.M. and Acoustic Scattering, P. 476). The resonance of the edge-on strip could be reduced by making it thin enough ($\lambda/4 \times 2\lambda$)*. The backscatter of the edge-on strip has approximately the amplitude of that of the sphere of comparable size. It remained to determine an exact RCS solution for the edge-on strip. Since the geometry of the strip is so, simple a Moment Method solution could be obtained with enough accuracy as to be considered exact. Therefore, it was decided to use the strip for calibration.

b. Targets for cross polarized RCS measurements

The cylinder, spherically-capped cylinder, and prolate spheroid tilted at angles of 15° and 30° from the plane of symmetry were used for C-P targets. With such a tilt, the targets were rotated as in the co-polarized measurements (ϕ rotation).

In addition, an assortment of discs, strips, and flat plates were measured.

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*See L. Peters, 2-D Applications for Bodies with Edges in Modern G.T.D. Short Course Notes, Vol. I, Article 2.

The positioning problems encountered in the co-polarized measurements were compounded when the targets were tilted.

c. Results

To date, the cross-polarized measurement results are not in presentable form. The raw data have been taken but not yet referenced to the exact (Moment Method) RCS.

Measured C-P target data were in general lower, relative to background, than in the V-V and H-H measurements, demanding greater receiver sensitivity.

In order to generate as many spectral points as was available in the co-polarized measurements, and thus validate smoothing, it is necessary to supply an equal number of exact data points. As a first order check of system viability, we are proceeding with 1/20 the number of spectral points.

It is anticipated that the C-P results will be those predicted from V-V, H-H.

6. Summary of Swept Frequency System

a. Strength

i) Speed in obtaining a large number of points in the frequency domain without the need for nulling out background at each frequency.

ii) Phase is obtained as well as amplitude allowing for

a) Time domain transform

and

b) Centroidal smoothing

b. Weaknesses

i) Multiple interactions between target and background are <u>not</u> subtracted out.

ii) System drift (in frequency output and receiver sensitivity) in real time between target, background, and calibrate sphere runs is only partially controlled.

<u>Publications</u>

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E.K. Walton, "Analysis of Accuracy of Radar Backscatter Measurement System Using Phasor Compensation", submitted to IEEE Trans. on Antennas and Propagation, October 23, 1981.

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[1] Young, J.D. "Radar Imaging from Ramp Response Signatures", IEEE Trans. on Antennas and Propagation, Vol. AP-24, #3, May 1976.

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[3] Walton, E.K. and Young, J.D., "Radar Scattering Measurements of Cones and Computations of Transient Response", IEEE Trans. on Antennas and Propagation, Vol. AP-29, #4, July 1981.

[4] Walton, E.K., "Analysis of Accuracy of Radar Backscatter Measurement System Using Phasor Compensation", submitted to IEEE Trans. on Antennas and Propagation, October, 1981.

APPENDIX I

PROJECT TITLES AND ABSTRACTS

Project 529081 Improvement of Antennas for Underground Radar (Terrascan)

The objective of this program is to improve the sensing head (antenna) of the Terrascan underground pipe detector developed previously for Columbia Gas and manufactured by Microwave Associates.

Project 784589 Technique for Optical Power Limiting

This is a classified program.

Project 784652 An Advanced Prototype System for Locating and Mapping Underground Obstacles

The objective of this program is to develop a portable video pulse radar system for locating and mapping underground objects to a depth of 10-15 feet. The emphasis is on improving signal processing techniques and optimizing system performance to improve target resolution.

Project 784673 Advanced Numerical Optical Concepts

The objective of this program is the development of the technology for optical computing systems.

Project 784701 A Synergistic Investigation of the Infrared Water Vapor Continuum

This study proposes a thorough 3-year investigation of the water vapor continuum absorption in the 8 μm to 12 μm and in the 3.5 μm to 4.0 μm atmospheric transmission windows. This absorption has been the topic of several previous studies. However, serious questions still remain and the need exists for a definitive study in order to answer questions related to laser radiation propagation through the atmosphere and also for optimization of infrared imaging and sensor systems which depend on 10 μm infrared radiation. The Contractor will use a multiline stabilized CO_2 laser and a spectrophone to perform precision measurements of the absorption by water vapor broadened by nitrogen, oxygen and N_2-O_2 mixtures, over a 17-27^{o} temperature range.

AD-A119 895 OHIO STATE UNIV COLUMBUS ELECTROSCIENCE LAB F/G 9/5
JOINT SERVICES ELECTRONICS PROGRAM.(U)
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Project 710816 Block Funded Support for Electromagnetic Research

This is research in the area of electromagnetic radiation and scattering including: (1) extension of the Geometric Theory of Diffraction (GTD) for convex surfaces, edges, vertices and time domain solutions; (2) the GTD combined with the Method of Moments (MM); (3) extension of the MM codes utilizing polygon surface current patches and wire-patch attachment modes; (4) transient electromagnetic phenomena including target identification, radar imagery, K-pulse techniques and scattering from a thin, circular disk; and (5) improving the free space scattering range at The Ohio State University ElectroScience Laboratory to obtain accurate polarization matrix information on selected reference targets.

Project 710964 Analysis of Airborne Antenna Patterns

The objectives of this program are to: (1) improve the aircraft model for far field pattern computations by considering a more realistic vertical stabilizer; (2) study various ways to model more general antenna types such as a monopole in the presence of directors; (3) examine various flat plate simulation codes; and (4) compare various calculated results with measurements supplied by NASA (Langley).

Project 711353 Extending the Geometrical Theory of Diffraction Using the Moment Method

This is a 3-year basic research program to develop the theory for further extensions of the GTD using the moment method and to implement that theory into computer programs so that the usefulness of the research in various scattering and antenna problems can be demonstrated.

Project 711639 Superdirective Arrays

The objective of this study is the development of computer codes to analyze the performance of a circularly disposed superdirective array with the appropriate feed network.

Project 711679 Jam Resistant Communications Systems Techniques

The objectives of this program include (1) development and testing of a bit-synchronous time-division multiple-access digital communications system suitable for use by a large number of small (airborne) terminals in conjunction with larger ground stations, (2) the application of adaptive arrays for up-link antijam protection of this system, and (3) development of techniques, circuits and components for increased data rates, digital control, and interference rejection in high speed digital communications systems.

Project 711930 Radar Cross Section Studies

The objective is to establish the GTD techniques required to treat the radar cross section of missile and aircraft bodies.

Project 711964 Electrically Small Antennas

This three-year program of research into electrically small antennas has three phases: Phase 1 - a basic study to develop the theory, techniques and computer codes for electrically small antennas mounted on a general structure; Phase 2 - a study to develop the theory, techniques and computer codes for printed circuit antennas; and Phase 3 - a study to compare the K-Pulse concept with more conventional techniques for increasing the maximum data rate in pulse communications using small antennas.

Project 712242 Formulate Quasi-Optical Techniques for Antennas at UHF

The goal of this program is to increase the electromagnetic effectiveness of Navy ships by developing low cost, integrated, systematic EM design procedures.

Project 712257 Application of Optical Computing Techniques to Jet Engine Control

This program involves the following tasks: (1) survey and document control requirements for jet engines using information supplied by sponsor; (2) survey and document the field of optical computing as applied to jet engine controls; (3) generate a report listing the various schemes and comparing them for speed, information processing capability, and ability to withstand the necessary environmental conditions; and (4) make recommendations as to the scheme most likely to satisfy the requirements stated in (1).

Project 712331 Air-to-Ground Measurements, Processing and Analysis of Moving Tactical Ground Targets

An experimental study is proposed of the modulation induced by moving ground vehicles on the returns of a VHF airborne radar. Automatic target and classification procedures developed at the ESL using ground-based data will be extended to data obtained from the airborne radar.

Project 712527 Research on Near Field Pattern Effects

The objective is to continue present efforts on aircraft antenna computer code development in terms of combining the volumetric pattern analysis for the fuselage with the multiple plate solutions developed earlier. This solution must be efficient and of a form that it can be adopted to the fuselage-wing junction analysis treated previously.

Project 712604 A Meteorological Instrumented Range for Millimeter-Wave Sensors

This project will investigate instrumentation required for air-to-ground millimeter wave sensor performance measurements with emphasis on adverse weather environments.

Project 712661 RCS Studies of Jet Intakes

This project has been separated into two phases: 1) to predict accurately the RCS of jet intakes as a potential tool for aircraft designers; 2) to extend the necessary experiments to be made to confirm the above predictions so that the results would be of value in future target identification studies. These phases can be conducted independently and useful results will be generated by either phase.

Project 712673 The Infrared Spectral Analysis of CF_2Cl_2: Application to Atmospheric Detection and Abundance Measurements for Planned In-Situ Experiments

This is a program of research to study a portion of the infrared spectrum of the molecule CF_2Cl_2. Infrared spectroscopy has proved to be a very sensitive method for detecting the presence of the molecule in the atmosphere, but as yet, little laboratory data exists to aid in determining its atmospheric abundance from in-situ spectra.

Project 712680 Roof-Top Antenna Study

This program will analyze the complex receive voltages in several loop antennas comprising a roof-top direction finding system. Although the exact building and antenna geometry are complicated, the following simplifications will be made: 1) the loop antennas will be modeled by simple rectangular thin wire loops, with one or two feed ports; 2) the roof-top will be modeled by a planar L-shaped perfectly conducting ground plane. The dimensions of the L will be chosen to roughly correspond to the outline of the roof.

Project 712684 Advanced Adaptive Antenna Techniques

Three areas of work are suggested: 1) study the effects of element patterns and signal polarization on the performance of adaptive arrays; 2) study the performance of certain sophisticated jamming techniques against adaptive arrays; and 3) continue work on an adaptive array monograph.

Project 712742 Radar Measurement of Rain Cells

The purpose of this effort is to obtain a statistical characterization of the distribution of rain attenuation along earth-space paths. This is to be accomplished through the simultaneous measurement of path attenuation and radar backscatter. Supporting measurements of the path radiometric temperature and the ground rain rate are also proposed. The resulting data are to be analyzed to yield information which will permit a more accurate conversion of point rain rate statistics to path attenuation statistics.

Project 712754 Research on Fast Semiconductor Infrared Optical Spatial Light Modulators

The following studies will be undertaken: 1) collect data on free-carrier absorption of 10.6 micron light in GaAs as a function of light intensity and wavelength of radiation in the 0.9 micron range; 2) measure free-carrier Faraday rotation as a function of the number of carriers to determine the feasibility of the design; 3) study the feasibility of modulating the absorption of 10.6 micron light in the transition between the heavy and light hole states; 4) design a Numerical Optical Data processor and 5) survey domestic and foreign literature for phenomena that might be useful for optical modulation.

Project 712759 CTS/Comstar Communication Link Characterization Experiment

The angle of arrival and gain degredation of the COMSTAR D-3 beacon will be made until September, 1980. Analysis of the angle of arrival and gain degredation data will then be completed.

Project 712797 Perform Technical Measurement to Determine Whether Discriminants Exist in the Time/Frequency Domain That Will Allow Characterization and Classification of Ground Based Tactical Targets

Experimental measurements of the radar backscatter from a moving tactical ground vehicle will be made. The vehicle will be modified so as to identify the specific source of any induced modulation in the radar return. An experimental plan of operation will be developed and implemented which will allow measurement of the radar return from the tactical vehicle under the conditions imposed by the experiment. The basic radar used will be the transportable VHF, UHF, X-band system developed at this institution.

Project 712798 Derive Basic Understanding of Phenomenology Inherent in EM Scattering Characteristics of Stationary and Moving Tactical Ground Targets

Several types of theoretical studies will be performed with the objective of increasing the understanding of the problem of automatic identification of a tactical ground radar target. The features of interest will include the behavior of the stationary target as a function of frequency, and as a function of polarization. The moving target is quite complex, and the influence of moving substructures on the radar return must be included.

Project 712831 Microwave Oven - Worst Case Probing Analysis

The purpose of this investigation is to use numerical electromagnetic analysis techniques to study the leakage fields of a microwave oven to determine where the strongest fields exist.

Project 712838 Investigate Bistatic Scattering Characteristics of Moving and Fixed Targets to Determine Whether Discriminants May Exist That Will Allow Target Classification

The following is proposed: 1) design, build and test a bistatic modification to the present truck-mounted X-band radar system; 2) develop a test plan which will allow the measurement of the bistatic radar return of several tactical ground vehicles; 3) carry out the test plan at an appropriate site, coordinating the site selection and scheduling of the tactical ground vehicles with the appropriate agency; 4) conduct preliminary analysis of the data quality and identify appropriate target identification features of the resulting data; and 5) prepare a final report on this task including results of the data analysis.

Project 712861 Coal Pile Electromagnetic Sensing Research

This project involves a research program in electromagnetic subsurface remote sensing as applied to accurate estimation of the quantity of coal in a large coal pile. This problem is important to inventory control at coal fired generating stations in the electric power industry. Coal quantity depends on bot[illegible]ity and volume of the pile, and means for remote sensing of both of these parameters is sought.

Project 712875 Feasibility Study of Vehicle Tracking System

ESL will conduct a demonstration to determine the feasibility of an optical tracking system to locate the x and y positions of a point on a moving vehicle with an accuracy ± 6 inches for both x and y positioning. Both static and dynamic experiments will be designed to demonstrate this resolution capability. The experiments will be carried out on the VDA Pad using a system assembled from equipment currently available at the ESL. The equipment will allow us to demonstrate one dimensional position location with the desired accuracy.

Project 712949 Leaky Ported Coaxial Cable Embedded at a Uniform Depth in a Lossy Half Space

It is the purpose of this research to complete our theory appropriate for a planar interface and the extension of our computer code to obtain numerical results for the associated propagation constants and field configurations.

Project 712978 Antenna Technology Study

Analyze the effect of a multi-layered lossy dielectric planar surface that coats a perfectly reflective surface. Provide computer code which implements this analysis.

Project 312657 Study of Frequency Selective Surfaces

This study involves formulating and coding the reflection from a multi-layered frequency selective surface composed of loaded dipoles and dielectric slabs.

Project 713143 Analysis of Airborne Antenna Pattern Distortion Effects

Program to investigate the effects of multiple antennas within a common radome on antenna patterns. Includes the effects of cylindrical radomes, large ground plane associated with fuselages, and other obstacles, i.e., other antennas.

Project 713169 EO Device Signature Reduction

This is a classified program.

Project 713176 Xenon Probe Laser for Atmospheric Studies

The objective is to construct and test a versatile laser, rugged enough for field operation and tunable to various lines in the 2-11.3 μm range, for use as an atmospheric probe laser.

Project 713206 Advanced RCS Reduction

This is a classified program.

Project 713302 Design of Dual Band Antennas

The Navy frequently has need for antennas which will operate at more than one band of frequencies. This project addresses the design of a dual band reflector antenna utilizing a dichroic surface design that is based on extensive experience at the ElectroScience Lab with transparent metallic surfaces.

Project 713303 On-Aircraft Antennas

The objectives of this program are: 1) to develop the capability to analytically synthesize the aperture distribution of a complex antenna array given its free space near field antenna pattern; 2) to test the technique developed in item 1 by using simple antenna arrays; and 3) to investigate the accuracy of the Geometrical Theory of Diffraction as applied to a curved surface in terms of low scattering levels associated with side lobe illumination of such structures.

Project 713319 Measurement of Surface Ship Radar Backscatter at HF for Target Identification Studies

The objective of this program is to develop methods to measure radar backscatter from ships. A computer controlled radar cross section measurement system will be configured for the task of measuring the radar cross section of ship models.

Project 713321 Research on Near Field Pattern Effects

This study consists of the following: 1) develop a near field solution for the volumetric pattern of an antenna mounted on a 3-dimensional fuselage structure; 2) extend the present numerical analysis for near field principal plane patterns to treat multiple plates; 3) using these improved solutions examine their validity and usefulness in analyzing various complex airborne antenna problems; and 4) compare calculated results with measured results.

Project 312657 Study of Frequency Selective Surfaces

This study involves formulating and coding the reflection from a multi-layered frequency selective surface composed of loaded dipoles and dielectric slabs.

Project 713402 Microstrip Analysis Techniques

This study extends the state of the art in microstrip analysis techniques by considering mutual coupling between microstrip antennas on a flat strip and on a cylinder.

Project 312661 Radome Design

The objective of this study is to design a metallic radome to be placed inside an existing dielectric radome.

Project 713533 Engineering Calculations for Satellite Systems Planning

The objective of this program is to enhance the computational capability of NASA/Lewis Research Center for calculating the performance of proposed communications satellite systems. In particular, the effort addresses the potential interference between services sharing a common frequency band.

Project 713580 Radar Cross Section of Aircraft/Avionics Systems

This study involves the prediction of the RCS of selected portions of an airframe.

Project 713581 Development of Computer Models of Large Reflectors

The objective of this study is to develop computer models to provide design information for space-borne reflector antennas.

Project 529622 Gas Leak Detection

The objective of this program is to develop electromagnetic techniques for the location of leaks in underground gas pipes.

Project 529623 Terrascan Improvement

The objective is the development of an improved Terrascan unit for the location of buried pipes. Two areas are being addressed:
1) improvement of the sensor head (antenna) and 2) improvements in the ease of operation of the unit and its adaptability to a wide range of soil conditions.

Project 713645 MX Physical Security System

The objective of this program is to develop electromagnetic techniques for determining the electrical parameters of soil in situ.

Project 713671 Conduct Exploratory Development of Millimeter Wave (MMW) Systems Using the Targeting Systems Characterization Facility (TSCF)

The objective of this study is to assess the effects of target and background signatures, meteorological conditions, and sensor-to-target geometries of the TSCF on MMW radar and radiometric measurements, to recommend appropriate design modifications and calibration procedures and to provide technical and computer software support for TSCF MMW measurements.

Project 713712 Evaluation of Design Candidate Antenna

The objective of this study is to analyze the performance of a design candidate antenna with a tunnel. Computer models are to be developed for the scan plane so that worst case performance can be predicted.

Project 312688 Geophysical Research

The objective of this program is to determine the state-of-the-art in underground exploration using electromagnetic techniques and define a program for an electromagnetic exploration system (EMES).

Project 713731 Data Processing of Radar Measurements

The objective of this program is to digitize a collection of data on radar backscatter from moving tactical ground vehicles and store the data on computer compatible tape files for future processing.

Project 713758 Basic Computer Code Development

The objective of this program is to extend the ESL basic scattering code to include higher-order scattering effects and impedance loaded surfaces.

Project 713768 A Theoretical and Experimental Study of a Potential Mobile System for Evaluating Electrical Parameters of the Earth

The objective of this study is to evaluate a novel approach for rapidly estimating the electrical parameters of the earth over a broad frequency band.

Project 713774 The Effects of Atmospheric Water Vapor on Infrared Propagation

The objective of this program is to make measurements of the absorption of infrared radiation by pure and pressure-broadened water vapor samples at several different frequencies using a frequency-doubled CO_2 laser. Results of these measurements are to be incorporated into an analysis of continuum absorption as wings of strong absorption lines.

Project 713971 Computation of the Performance of an Element Antenna Array Mounted on an Aircraft

The objective of this program is to compute the radiation patterns of a specified set of antenna elements and a specified frequency range to insure adequate SINR (signal to interference plus noise ratio) over a specified field of view. Array performance is simulated to represent an adaptive mode of operation.

Project 714100 Navigation System Simulation

The objective of this program is to evaluate the simulation and performance of the GPS/JTIDS Adaptive Multifunction Array antenna design.

Project 714119 Support Services of Electromagnetic Design of RAM/RAS and Non-Specular Scattering

This is a classified program.

Project 714152 Frequency Sensitive Surface (FSS)

The purpose of this program is to design a frequency sensitive surface (FSS) to be comprised of two or three loaded dipole arrays sandwiched between an appropriate number of dielectric slabs.

APPENDIX II
ELECTROSCIENCE LABORATORY SPONSORING AGENCIES

OHIO STATE UNIVERSITY - ELECTROSCIENCE LABORATORY ACTIVE PROJECTS DURING OCTOBER 1980 - OCTOBER 1981

PROJECT ENGINEER	PROJECT NUMBER	SPONSOR	CONTRACT OR GRANT NUMBER	STARTING DATE	ENDING DATE	AWARD AMOUNT	SOURCE
	Facilities Contract		AF 33(600)-31168				
YOUNG	529062	Columbia Gas					
YOUNG	529081	Gas Research Inst.		06-01-79	05-31-80	59K	
MEADORS/WALTER	784589	AFSC	F33615-77-C-1011	10-18-76	08-31-81	302K	02
CALDECOTT	784652	EPRI	RP7856-1-5	01-01-77	12-31-81	600K	03
COLLINS	784673	BMDSC	DASG60-77-C-0045	03-01-77	03-15-81	249K	02
NORDSTROM/LONG	784701	ARO	DAAG29-77-C-0010	04-01-77	09-30-80	208K	01
WALTER	710816	ONR	N00014-78-C-0049	10-01-77	09-30-82	1607K	01
BURNSIDE	710964	NASA/Langley	NSG 1498	01-16-78	01-15-82	169K	02
KOUYOUMJIAN	711353	ESD	F19628-78-C-0198	09-01-78	08-31-81	123K	01
NEWMAN	711639	NSA	MDA904-79-C-0407	10-24-78	12-31-81	178K	03
KSIENSKI BURNSIDE	711679	RADC	F30602-79-C-0068	12-04-78	08-03-84	1049K	02
PETERS/BURNSIDE	711930	NASA/Langley	NSG 1613	05-01-79	04-30-82	237K	02
RICHMOND WALTER	711964	ARO	DAAG29-79-C-0092	05-01-79	04-30-82	154K	02
MARHEFKA/RUDDUCK	712242	NOSC	N00123-79-C-1469	08-01-79	07-31-82	375K	02
COLLINS	712257	NASA/Lewis	NSG 3302	08-01-79	07-30-82	164K	02
WALTER	712331	Clarkson College	F30602-78-C-0102	08-14-79	05-15-81	35K	02
BURNSIDE	712527	NASC	N00019-80-C-0050	11-29-79	09-30-82	190K	02
LEVIS	712604	Clarkson College	F30602-78-C-0102	01-02-80	05-15-81	48K	02
PATHAK	712661	ESD/Hanscom AFB	F19628-80-C-0056	04-01-80	03-01-82	147K	02
DAMON	712673	NASA/Washington	NAGW-31	02-01-80	04-30-81	30K	01
NEWMAN	712680	Southwest Research	P.O. 89694 5W	02-18-80	01-08-82	91K	02
COMPTON	712684	NASC	N00019-80-C-0181	02-11-80	03-22-82	155K	02
LEVIS	712742	Intelsat	INTEL-066	03-20-80	03-19-82	168K	01
THURSTON/COLLINS	712754	BMDSC	DASG60-80-C-0037	03-18-80	06-30-81	65K	01
LEVIS	712759	NASA	NASW-3393	03-15-80	03-31-82	395K	02
KSIENSKI	712797	Clarkson College	F30602-78-C-0102	03-28-80	05-15-81	47K	02
KSIENSKI	712798	Clarkson College	F30602-78-C-0102	03-28-80	05-15-81	47K	02
NEWMAN	712831	Whirlpool Corporation		04-15-80	12-15-80	20K	02
KSIENSKI	713838	Clarkson College	F30602-78-C-0102	04-16-80	05-15-81	47K	02
YOUNG	712861	TVA	TVA-53983A	04-17-80	09-30-82	163K	01
POIRIER/SVOBODA	712875	NHTSA	OSU-80-0013	05-08-80	09-30-82	91K	02
RICHMOND/GARBACZ	712949	Waterways Exp. Stat.	DACA39-80-K-0001	05-01-80	03-31-82	105K	01
RUDDUCK	712978	Lockheed	DB50C6160F	06-09-80	11-30-80	92K	02
MUNK	312657	Ford Aerospace		05-01-80	11-30-80	28K	02
BURNSIDE	713143	SCEEE	SCEEE-PDP/80-25	07-15-80	12-31-81	83K	02
DAMON	713169	ASD, WPAFB	F33615-80-C-1072	08-01-80	02-01-83	193K	01
DAMON	713176	NRL	N00173-80-C-0416	08-01-80	07-31-82	50K	03
MUNK	713206	ASD,WPAFB	F33615-80-C-1086	08-25-80	08-24-83	300K	02
MUNK	713302	NRL	N00173-80-C-0367	09-30-80	12-31-81	98K	03

PROJECT ENGINEER	PROJECT NUMBER	SPONSOR	CONTRACT OR GRANT NUMBER	STARTING DATE	ENDING DATE	AWARD AMOUNT	SOURCE
RUDDUCK	713303	NADC	N62269-80-C-0384	09-22-80	09-30-82	100K	03
KSIENSKI/WALTON	713319	NRL	N00173-80-C-0466	09-17-80	03-31-82	60K	02
BURNSIDE	713321	NASC	N00019-80-C-0593	09-29-80	09-28-81	65K	02
NEWMAN	713402	ARO	DAAG29-81-K-0020	11-01-80	10-31-82	102K	02
MUNK	312661	Martin Marietta		07-01-80	09-30-81	19K	03
LEVIS	713533	NASA/Lewis	NAG 3-159	01-20-81	07-15-82	93K	01
PETERS/BURNSIDE	713580	Rockwell International	L1XM-11296-915	01-26-81	07-31-81	60K	02
RUDDUCK	713581	Martin Marietta	RH1-092665	01-21-81	06-30-82	92K	03
YOUNG	529622	Gas Research Institute		01-19-81	01-19-82	101K	02
YOUNG	529623	Gas Research Institute		01-26-81	01-26-82	125K	02
YOUNG	713645	Boeing Aerospace	F55411	03-05-81	12-31-81	160K	02
LEVIS	713671	ASD, WPAFB	F33615-81-C-1437	04-01-81	07-31-82	47K	01
RUDDUCK	713712	Aerospace Corp	P.O. 27809-AN	04-01-81	06-30-82	55K	02
WALTER	312688	Terra Research		03-15-81	Indefinite	10K	03
KSIENSKI/WALTON	713731	ASD,WPAFB	F33615-81-C-1490	05-01-81	01-01-82	71K	02
WALTER/MARHEFKA	713758	Lockheed	DA5006340F	04-22-81	12-15-81	24K	03
PETERS	713768	NSF	ECS-8020636	05-01-81	04-30-83	60K	01
DAMON/LONG	713774	ARO	DAAG29-81-K-0084	06-01-81	05-31-83	200K	01
KSIENSKI	713971	Forsvarets Materielverk	FK 82463-80-409-23-001	07-06-81	01-31-82	30K	02
KSIENSKI	714100	Analytic Sciences	10300	09-01-81	09-30-83	95K	02
MUNK	714119	McDonnell Douglas	P.O. Z10104	09-04-81	09-30-82	35K	03
MUNK	714152	Ford Aerospace	SP-720849-AX	07-16-81	12-07-81	30K	02

APPENDIX III

REPORTS PUBLISHED BY ESL OCTOBER 1980 TO OCTOBER 1981

710816-9 ELECTROMAGNETIC SCATTERING BY OPEN CIRCULAR WAVEGUIDES, T.W. Johnson & D.L. Moffatt, December 1980. Dissertation.

710816-10 JOINT SERVICES ELECTRONICS PROGRAM, THIRD ANNUAL REPORT - October 1979-October 1980, December 1980

710964-7 ANALYSIS OF PRIVATE AIRCRAFT ANTENNA PATTERNS - SEMIANNUAL, W.D. Burnside, October 1980.

710964-8 GTD ANALYSIS OF AIRBORNE ANTENNAS RADIATING IN THE PRESENCE OF LOSSY DIELECTRIC LAYERS, R.G. Rojas-Teran, August 1981. Thesis.

711353-2 A HYBRID METHOD WHICH COMBINES A MOMENT METHOD CURRENT WITH AN ASYMPTOTIC CURRENT, T.J. Kim & G.A. Thiele, December 1980. Dissertation.

711559-1 ANNULAR SLOTS WITH CARIODID-TYPE PATTERNS, Koichi Ayabe & B.A. Munk, October 1980.

711679-5 A FOUR-PHASE MODULATION SYSTEM FOR USE WITH AN ADAPTIVE ARRAY, Jack H. Winters, July 1981. Dissertation.

711679-6 DEPENDENCE OF ADAPTIVE ARRAY PERFORMANCE ON CONVENTIONAL ARRAY DESIGN, Inder J. Gupta & A.A. Ksienski, August 1981.

711964-3 ELECTRICALLY SMALL ANTENNAS, SEMIANNUAL, J.H. Richmond & C.H. Walter, January 1981.

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